DESIGN AND DEVELOPMENT

OF A

PACK SYSTEM

FOR PORTABLE GPS DEVICES

by
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A Master's Degree Project
submitted to the Faculty of Environmental Design
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PROJECT ABSTRACT

This Master's Degree Project is inspired by the deficiencies of backpack systems currently in use for carrying portable Global Positioning System (GPS) equipment. The project examines the sophistication of general backpack designs and considers which features could be applied to produce a more ergonomically friendly carrying system for portable GPS equipment, based on feedback from the field.

The focus of this Masters' Degree Project is on existing technology applied to a design problem. It does not develop new scientific knowledge but rather assembles existing knowledge for the benefit of a specific end user group.

Backpack conceptualizations were developed from paper models and sewn mock-ups.

- They were then evaluated for:
- construction
- ease of use
- fit
- features that aided work activities.

The final design is the result of two prototype models that were field test for sixteen weeks before the appearance model was constructed.

The research included:

- a literature search of ergonomic considerations pertaining to backpack use
- task analysis
- interviews and a survey with the specific end user group
- a market study of similar equipment backpacks
- a focus group of experts to establish guidelines for the design
- a literature review of backpack construction and textiles to obtain a set of useable materials for the design.

The hypothesis is that end user considerations could be incorporated to the carrying of the portable GPS equipment. The objective was to enable a surveyor using the new portable GPS backpack equipment for coal pit mine activities, to complete work activities in a more efficient manner and without the back discomfort typical of current carrying systems. The resulting design satisfies a predetermined market segment, and may also demonstrate to the market the importance of potential specific end user considerations.

ACKNOWLEDGMENTS

I wish to thank Professor Jim O' Grady, Dr. Elizabeth Canon, and Dr. Crooks for their guidance, recommendations, and encouragement for this project. Their assistance with this project has been invaluable to its outcome.

I would also like to thank Line Creek Mine, Luscar Ltd., Linda Martin, Phil Pascuzzi, and Stacey Allan, who provided the opportunity and learning experience to carry out the project of designing a carrying device for portable GPS equipment; which included documentation and assessment of the equipment.

Finally I must give special thanks to Ray Beich, John Kinnear, Tim White, Lyle Douglas, numerous other surveyors and engineers, who provided invaluable assistance and information (in the form of various studies), for which I am extremely thankful for.

In addition, I must thank Novatel for the assistance they provided by loaning expensive equipment for investigation. The staff was extremely helpful with explaining systems, showing the future of GPS equipment, and genuine in promoting education about what they do.

1. PROJECT OUTLINE

1.1. INTRODUCTION

LineCreek Mines have identified a problem with the current GPS (or Global Positioning System) backpack equipment. The employees who use the equipment have complained of back discomfort and awkwardness of use. Upon analysis of the current equipment, it is noted that little consideration of the user is applied to carrying the equipment. The goal of the project is to determine a solution to the problem. In essence, this project is completely client driven requiring a design solution.

Portable Global Positioning System stations, or simply GPS as the equipment will be referred to, are the most productive survey tools ever developed. Jobs that once required a full survey crew can now be handled by a single surveyor. With the ability to get centimeter positions in seconds, most users in the field report increases in productivity well over 100%. This assertion is based on cost (one person with equipment not a crew), accuracy (with GPS several radio systems use "differential" techniques in which a stationary surveyed station broadcasts its measured offsets that are applied by nearby receivers to correct their own measurements - increasing accuracy by a factor of five), autonomy, and less potential for human error (navigation and calculations are automated, humans determine waypoints and only monitor equipment failures) (Kaytom, 1990, p. 1 - 2). There are two major uses for GPS in this particular application. Firstly, for the client - LineCreek Mines, the most important use is in the Material Resource and Land Management. More than before, the pressure is on the fine line of economic viability and ecological sustainability. Effective management can only be achieved with useful and reliable information. Secondly, and as important, the system is used for environmental monitoring and scientific research. Thirdly, a daily activity within the mining operation requires the marking of blast sites using GPS. Production at the mine is highly dependent on the surveyors activities.

The survey employees of LineCreek Mines, deal with enormous numbers of assets, spread over huge distances and diverse terrain; mostly in bush and thickly forested areas on steep inclines (includes extreme avalanche hazard areas), and also within dangerous pits of the local mine site. Keeping track of the number, position and quality of assets is a time consuming, expensive, and arduous task. Vital details need to be recorded and updated. Because these employees use the equipment day in and day out, it has been noted that the backpack used does not necessarily suit their use. One particular backpack is severely damaged (not repairable) leaving only two somewhat useable backpacks available to be shared amongst employees. The result is substandard operation; with employees complaining of back discomfort.

The equipment is expensive ranging from $30,000.00 to $40,000.00 per station (a unit that includes a backpack, GPS and radio receiver, antennae, battery(ies), various cables, and a data collection/input device). Based on all of the above, a request was made by the management team of LineCreek Mines to research the problem and to arrive at a solution.

This MDP is written in an American Psychological Association publication style, and divided into three sections. The first Section, Chapters One through Three, is an overview of the approach taken and the background information. Chapter One and Three describe a project plan with necessary tools that contribute to the successful completion of the project. Chapter Two is an exploration of why we carry items and examines issues that are important to backpack design. The role of GPS equipment is also examined as it is relevant to the project.

The second section sets the context for design activity. Chapter Four reports the evaluation of the use of the backpack for carrying GPS equipment based on ergonomic significance, and in its field context. This Chapter looks at the measurements, weight distribution, and cable management that is necessary for the project. It then includes options for the design work to determine the best design for use in its context (based on significant work activities, feasibility, and contribution to efficiency).

The final section describes the design process. Chapter Five starts with a plan for design work that is iterative. The Chapter is a demonstration of the sequence of design development and includes steps taken to solve specific problems. Finally, the project is summarized in Chapter Six. This MDP implies that only by analyzing the specific use of a product can it play a major role in product design.

1.2. METHODOLOGY

The planning process for the project included the identification of necessary steps to be taken. The approach is a series of investigative strategies and a visual model of the plan. **Figure #1** is the visual model used for the project plan. The stages of investigation are:

1. Identify applicable literature - a thorough investigation took place to discover previous work relating to the project.
2. Outline Initial Design Concepts - create ideas to establish a frame of reference for the project.
3. Identify subjects - the client specified the user group which participated in a two-part interview, survey and task analysis.
4. Refine Design Concepts - using information from the subjects, further design ideas were generated and mock-ups and working models were made.
5. Identify a control group - this group participated in a focus group to identify any possible design features missed and to measure consistencies or inconsistencies in the specific use of this type of backpack.

6. Test Designs - the identified subjects field tested two different backpack designs over a period of sixteen weeks.
7. Final Design Concept - determined by all available information which includes the results of the field testing.

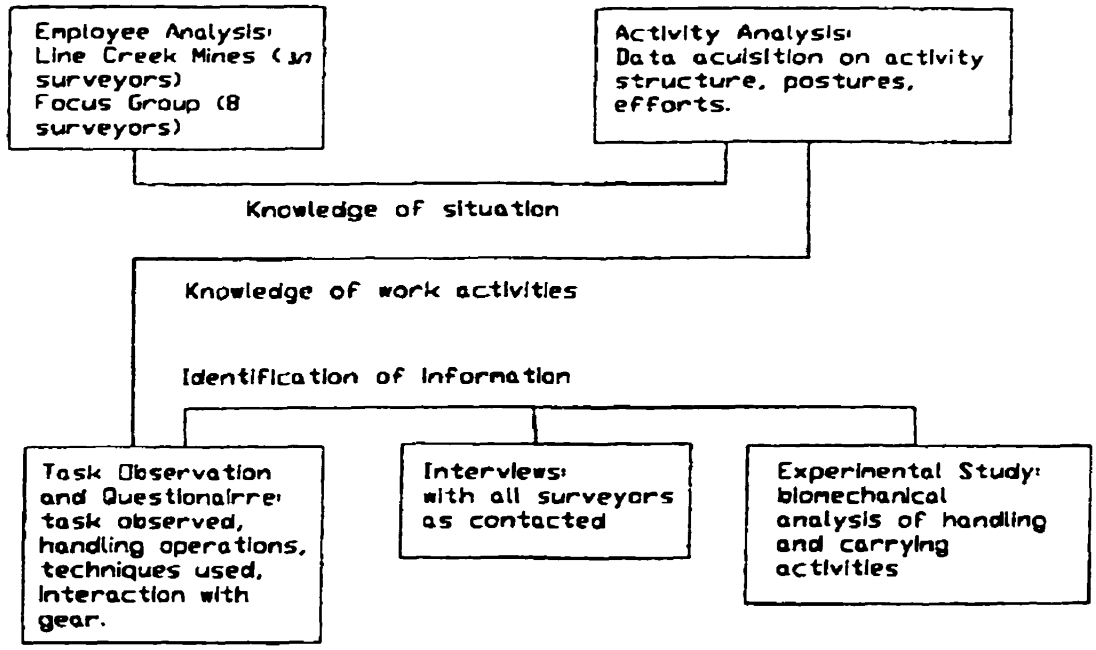


Figure #1 – Knowledge Obtaining Plan

The document is divided into background information, research and findings, and design work. However, the actual process followed this path:

i.) Concept generation with little information
ii.) Product investigation
iii.) Task analysis
iv.) Focus group with study models
v.) Design generation
vi.) Background investigation
vii.) Field testing
viii.) Further investigative research, and
ix.) Final design development.

The Appendices follow along with the actual project. Appendices 1 through 5 present the questionnaire, consent process and other documents required to execute the project. Appendices 6 through 8 present human function considerations. Appendices 9 through 13 present project evaluation documents. Appendices 14 through 16 present the final design construction pieces.

2.1. THE HISTORY OF CARRYING

2.1.1. THE DISCOVERY OF WHEN MAN FIRST CARRIED

The following section on the historical interpretation of carrying was adapted from The Big Bag Book, Houck & Miller (1977), New York: Scribner Books, Chapter One.

Archeologists and researchers have spent much time piecing the story together of what man did when. Man is equipped with a large brain and an opposing thumb, a unique combination that lead to civilization. Man discovered he could hold things in his hands, which led him to realize that he could carry things in his hands. When he found a bush overflowing with berries, he found his two hands were inadequate to carry home all that he could pick.

Historical research shows evidence that man's brain worked to solve those types of problems. Unfortunately, many things that were done occurred before the recording of history. Researchers whose profession is to "tell the story", have a few ideas. One idea is that man found a large leaf, laid the berries in the center, and pulled the edges together. He could carry two or three leaves full of fruit to take home to his hungry family.

Figure #2 – Use of Leaves and/or Reeds to Carry Food

Figure #2 (Englebert, 1992, p.168) depicts the use of carrying food with leaves or reeds. Around 25,000 BC animal skins began to be used for carrying and for clothing.

Figure #3 – The Construction of Vessels Using Various Materials

Figure #3 (Englebert, 1992, p, 157) shows a combination of animal skin and weaving to create a vessel;

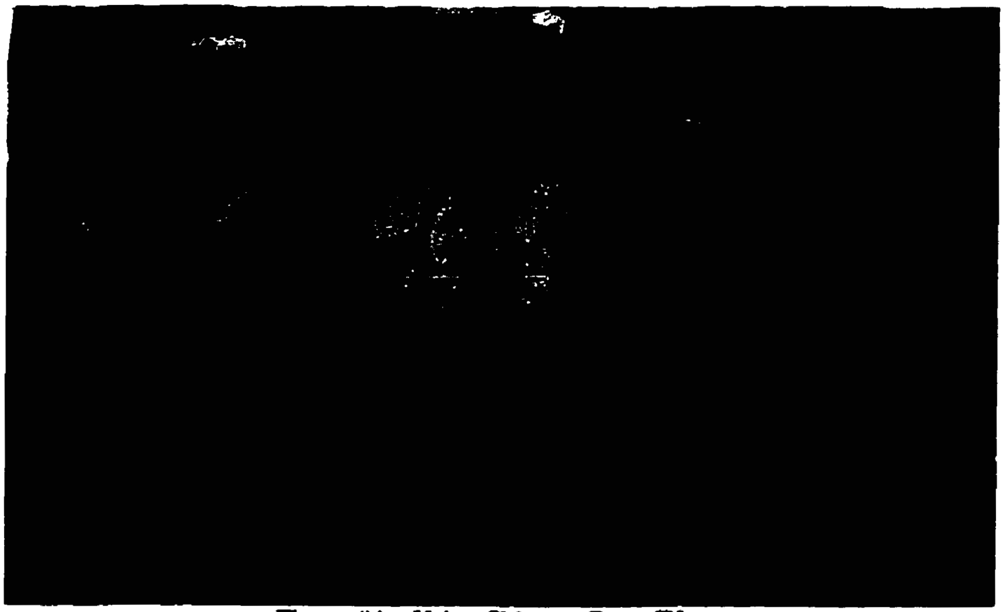


Figure #4 – Using Skins to Carry Water

Figure #4 (Englebert, 1992, p.92) shows to use of an entire animal hide for the purpose of carrying water. Around the same time, long strands of grass were woven together into mats. These mats were also used to carry items by pulling up at the corners and securing them.

Figure #5 – Woven Mats Used as Luggage

Figure #5 (Englebert, 1992, p.75) demonstrates the use of mats for packing items when on the move. They could even be hung on the ends of sticks.

The invention of the needle dramatically changed how people wore clothing and how bags were made. When a mat was folded and seams made down each side, more could be carried with less falling out. That original square pulled together at the corners never died.

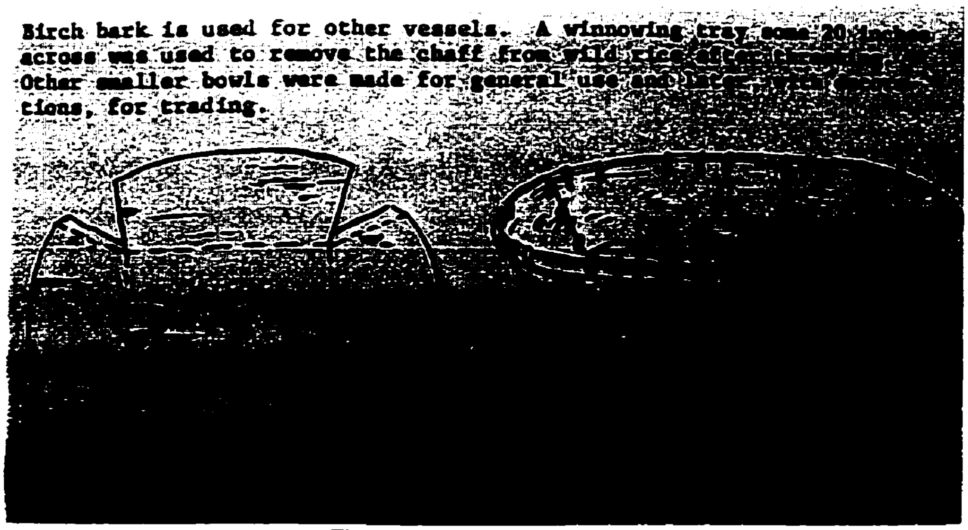


Figure #6 – Bark Container

Figure #6 (VanNostrand, 1972, p.205) shows a basic shape and pattern used by North American Indians. Today that shape has progressed in size, shape, and usefulness.

Throughout time, the bag has continuously mirrored occupations and aspirations.

In many civilized countries, bags became status symbols ie. the Doctors bag. There is a direct parallel with the medicine man who carried a special bag with magic properties that impressed members of the tribe.

Decoration became a large part of bag making. The design and decoration of bags have reflected all manner of artistic movements from Art Nouveau to Pop Art. **Figure #7** and **Figure #8** (Mazza, 1996, p.181) are examples of Pop Art bags.

Figures #7 and 8 – Pop Art Bags

Designers can apply fantasy as well as purpose and practicality to a bag. Originally, decoration had a significant purpose. An example of this would be the medicine man's bag, often covered with such valuables as rare bird feathers, beaded symbols, and bones or shells. **Figure #9** (VanNostrand, 1972, cover page) is an example of a highly decorated North American Indian bag. Today, some application of decoration also has a significant purpose, an example of this would be reflective tape sewn on backpacks for increased visibility.

In every part of the world, some version of a small belt purse can be found. Both men and women have worn them. The Roman toga was folded and draped in a way that created a large pocket for carrying necessities. Later, European clothing did not include pockets, so a hip belt came into being. Scottish Highlanders wore a sporran that hangs on a chain on the front of the pocketless kilt. During the time of arrows and guns, men often wore bags for arrows and ammunition on a belt or over the shoulder. In Medieval times, women wore scissors and keys hung on their neck as a sign of being a wife. In addition, they wore small purses from their belts. The more the woman had hanging from her belt the more affluent she was.

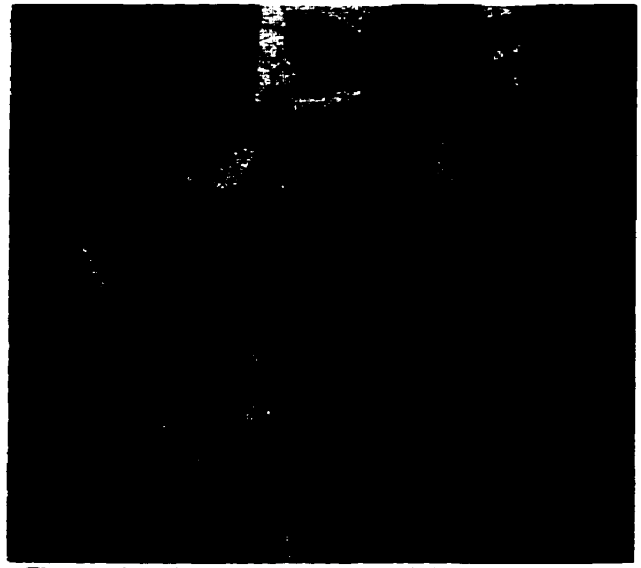


Figure #9 – North American Aboriginal Beaded Bag

When clothing incorporated pockets, the importance of bags diminished. However, their meaning did not change. The changes in its shape and purpose have charted social developments. From Medieval time through the Victorian era, bags were knitted, crocheted, woven, netted, and sewn. An example of a netted bag is shown in **Figure #10** (DeLeon, 1978, p.124).

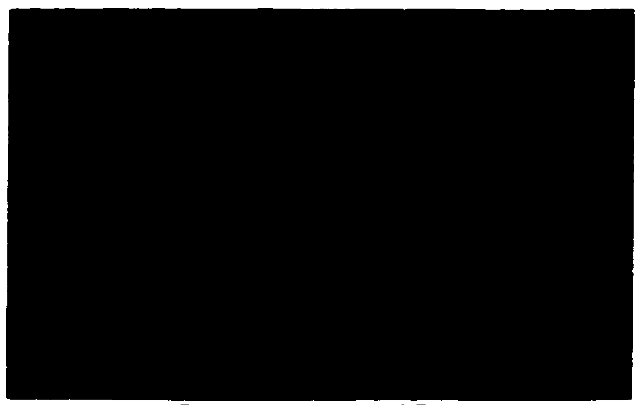


Figure #10 – Netted Bag

Throughout Western civilization, bags have demonstrated their importance. The English country gentleman used an elegant leather bag for the game he shot. A poacher would use a cloth sack to drag home game from the hunt, coal, grain, or whatever else he acquired. Wealthy women had the "Chatelaine" bag, while the servants used their aprons. Couriers carried papers, money, and important documents in saddlebags. Cowboys carried their guns in holsters and ammunition in bullet bags. The hobo carried his worldly goods in a bandanna.

All over the world women have carried their babies in large bags over their shoulders or in the middle of their back. The grain that was sown was carried in a shoulder bag hung at hip level. There were skin bags for water and wine, saddlebags for journeys, and string bags to carry supplies. (Houck & Miller, 1977, pages 1 to 6).

Not much has changed. Bags are still practical, attractive, and indispensable in life. They can be plain and/or business-like, decorated and/or personalized. They can be made of a range of materials such as silk, thick tapestry, cordura, muslin, or polyvinyl chloride (PVC).

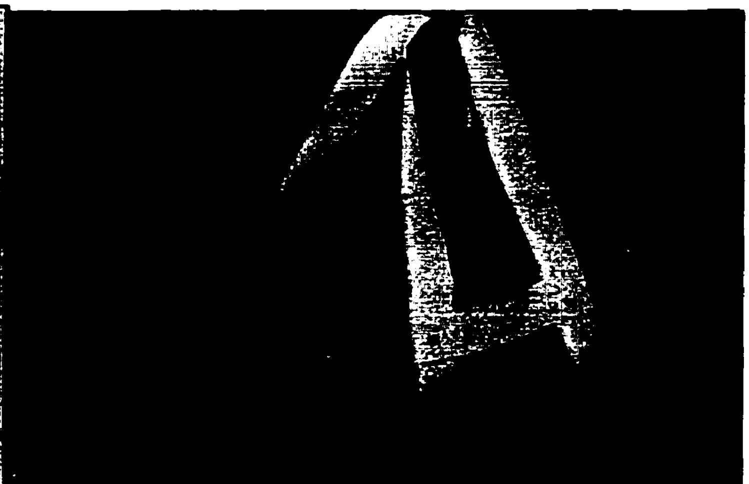


Figure #12 – Using Found Natural Objects

Figure #11 – Leather Bag

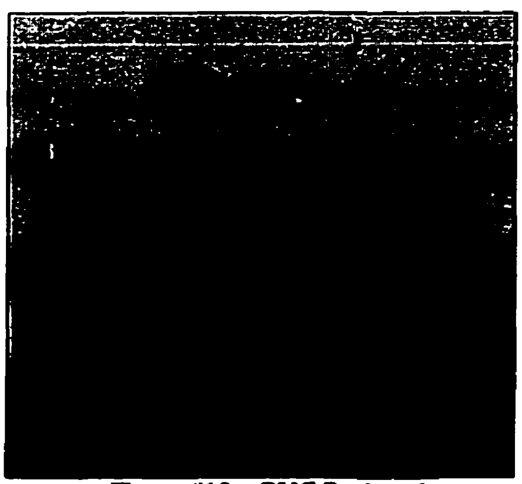


Figure #13 – PVC Backpack

Figure #11, #12, and #13 (Mazza, 1996, p. 23, 174, 109) are all examples of different materials used for different purposes, whether the reason is fashion related, art related, or simply to make a statement.

2.1.2. CURRENT BAGS

If you look around, most people are carrying or wearing a bag, or even have a combination of both. You may see a woman with a purse, a shopping bag, and a briefcase or a man with a backpack and an attaché case.

Tote bags and shopping bags are an important facet in our mobile society and have become an important form of advertising. **Figure #14** (Mazza, 1996, p.132) clearly demonstrates the shopping bag used for advertising; although the shopping bag can also be a gratuity for purchasing certain items and a status symbol. The casual approach to clothing has us packing our clothing in tote bags. Softer and lighter suitcases make travel easier and more practical.

Figure #14 – Shopping Bag

Every sport has a specific bag made for the equipment. From a bag that holds a tent, to a golf bag, or a tennis bag compartmentalized for each piece. Hikers, snowboarders, and skiers use belt packs and backpacks in all sizes and shapes. Beach bags open out into mats and some bags can also be inflated and used as floatation devices.

Household bags are used for storing and organizing. Clothing bags, shoe bags, and blanket bags protect items to keep them in good condition. In addition there are laundry bags to contain soiled clothing, vacuum cleaner bags to collect dirt, and bags specially fitted for China and silverware.

Some bags are game bags that open out for checkers, chess and backgammon. Gifts are also presented in bags replacing wrapping paper.

Industrial bags are used to protect items and make them easier to carry. Camera bags, musical instrument bags, and product bags for sales people are all industrial bags. Many of these bags are custom-made for special purposes and exactly fit the equipment. They are measured to fit, come in any color (quite often black or gray for a professional image), made of different materials, and can be personalized with monograms.

It is worth mentioning here that the history of bags used for venturing into the wilderness, has been lost in antiquity. An identifiable step toward a specific backpack occurred in the late 1920's. These types of bags are said to come from a military background, such as the classic "Haversack" from World War I. Army and Navy gear from World War II had an impact on backpacks, but the greatest evolution occurred in the 1960's when designs of these bags were refined.

2.1.3. CHRONOLOGY OF BAGS

PRE 25,000 BC	evidence that man used leaves for carrying
25,000 BC	the caveman used hides for carrying
1300 BC	woven grass mats used for carrying; more refinement in the shape of hides for carrying; animal stomachs used for carrying
1194 BC	togas with a folding pouch; belt pouches
800 BC	belt pouches; arrow bags; medicine bags
300 AD	refined belt pouches; utility pouches; arrow bags; netted and knotted bags
1200-1500 AD	with the invention of the needle bags were made in many more shapes; no longer only used for carrying and working, they imparted style and status statements too
1600-1800 AD	bags become more stylish; the more ornate belonged to the upper class; weaving becomes more refined and bags were woven, knitted, and netted; leather tooling made hunting bags and saddlebags a status symbol
1900 AD	bags become more useful for more tasks as man solves more problems of transporting items

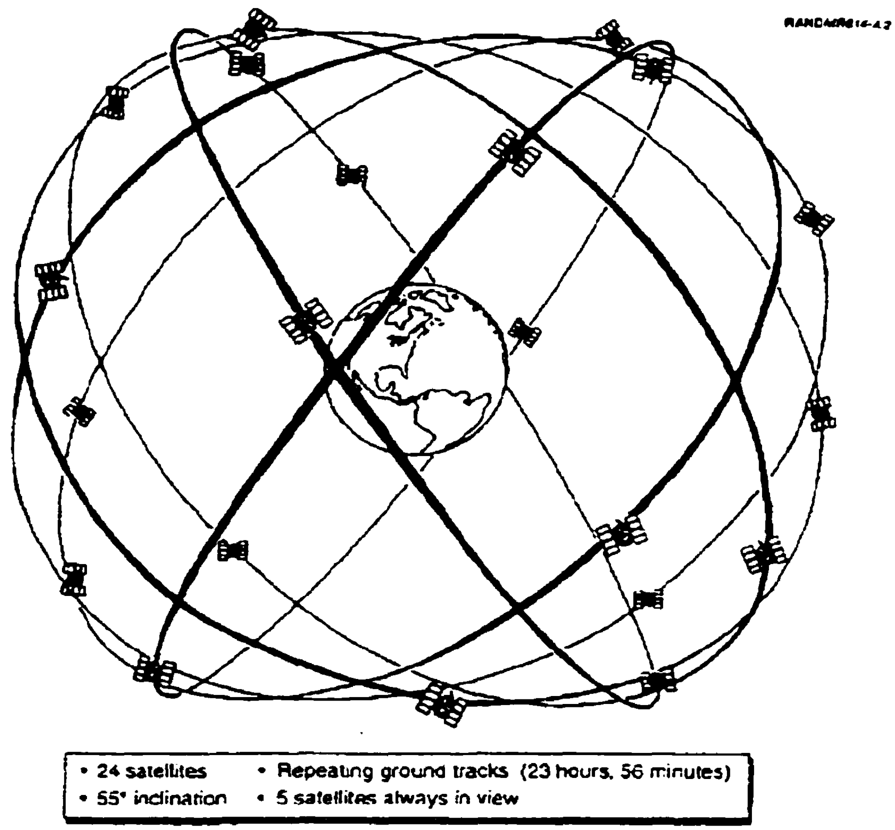
1940s	war and military use advance the design and use of bags
1960s	with the invention of new materials, and a concern for design the bag reached another level of sophistication; the paper bag for shopping became the norm in civilized society
1980-1990s	with a more casual trend in fashion and advancements in materials and textiles, bags remain trendy and soft designs morphize; there is a bag for just about everything and anything.

2.2. GPS EQUIPMENT

GPS equipment is an integral part of this design project. For the purpose of this project, it was necessary to understand why surveyors carried this particular system and why certain elements of this system are important to surveyors performing their work activities. The technological or engineered aspects of GPS equipment are beyond the scope of this project. Therefore, the investigation of GPS is limited to an understanding of how it was used in this application.

GPS is the most sophisticated system of pinpointing a position on earth so far developed by man. GPS was conceived in 1960 and developed under the auspices of the U.S. Air Force. In 1974, the entire U.S. military service was involved, and the system was declared fully operational in 1994. It cost $10 billion to develop. Twenty-four satellites circle the globe every 12 hours to provide global coverage. **Figure #15** shows the arrangement of the satellites. GPS receivers pick up the signals from a group of the twenty-four satellites, calculate locations and display numbers called coordinates, on a data device (Kaytom, 1990).

GPS is ideal for surveying. The system utilizes specialized cordless receivers that are within centimeters accuracy. Even though the particular system used in this project can continuously process data by tracking 12 satellites simultaneously, the external antenna is critical. The satellite signals are collected by the antenna and pass through a cable, which intensifies the signals, which are directed to an electronic circuit called a channel. The system employed at LineCreek Mines has five channels to quickly obtain position information from many satellites simultaneously



—GPS Constellation

U.S. Department of Defense and U.S. Department of Transportation. *1994 Federal Radionavigation Plan*. National Technical Information Service. DOT-VNTSC-RSPA-95-1/DOD-4650.5, Springfield, VA, May 1995 (Appendix A, p. 34).

Figure #15 – GPS Constellation

Given all of its potential, the system does have some limitations. The satellite signals cannot penetrate dense vegetation, rocks, and land forms. The receiver would not work in thick forest, narrow valleys, or among some blast site corridors. But, given the above limits, the receiver can pick up satellite signals through heavy fog and storms.

In addition to the GPS receiver and external antenna, surveyors also carry a radio receiver and an external radio antenna. Survey information is gathered by radio signals from towers in the mountainous area of the S.E. corner of the province of British Columbia. The radio receiver records signals and the time differences between other signals. Using tower locations, signal speeds and time differences, positions can be calculated. Both systems are used as one complete system for two reasons.

One, as a back-up for missed information from signals not being picked up because of terrain or weather; and two, to cross check the information for accuracy in order to save time and money. Both sets of data can give the mining engineers the information they need to map for production.

The surveyor's system is proprietary based on how the equipment was set up for their use and how it was decided what was needed. In addition to the software for the computer at the office, the receiver can only receive data from the data input device based on a proprietary format designed by the manufacture for the mine.

The data input device is a hand held unit attached to the receiver by a cable. Information can be given to the surveyors from the computer. It is then transferred to the data input device via the receiver. Exact locations can be staked for drill holes at blast sites with this method. Waypoints or surveyed coordinates of a location can also be entered into the receiver via the data input device and then downloaded or transferred into the computer. This method would be used to measure a coal pile for inventory purposes.

Most survey activity is for production purposes. Some survey activity is for inventory, land reclamation, and some research.

The total equipment list for this system, the principal pieces of which are shown in **Figure #16** includes:

1. GPS data input device
2. GPS receiver
3. GPS external antenna
4. radio receiver
5. radio external antenna
6. one 9-volt battery; possibly two for all day projects and to reduce loss of time resulting from dead batteries; five cables

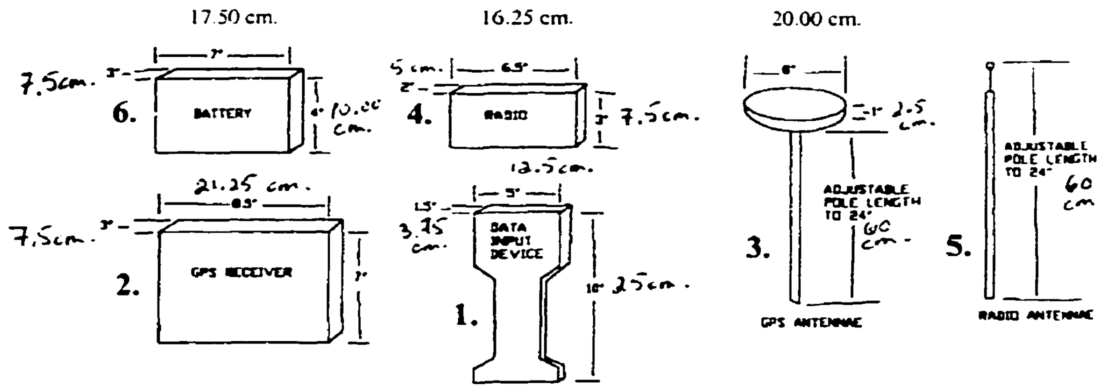


Figure #16 -GPS Equipment

Additional equipment carried depending on work activity:

- one or two cans of spray paint
- spray paint marking stick
- felt pens
- stakes (usually 1 bundle of 24 at one time); have placed as many as 100 or more stakes depending on what is required.

Information on system:

1. Weight: GPS receiver – 12.65 kg., radio receiver – 11.25 kg. , batteries – 14.00 kg., antennas – 10.50 kg., cables 12.00 kg., total (without backpack) = 60.50 kg.
2. Water resistant
3. Batteries - 9volt; continuous hours - 6
4. Coordinate systems: lat/long, UTM, OSBG, Maidenhead, Over & Up.
5. Accuracy - 1.5 cm.; satellites tracked - 12
6. Units - statute, metric, nautical
7. Navigational features - map datum - 134, waypoints - 1500, routes - 30, reverse route, goto, steering
8. Direction - bearing and magnetic + true North
9. Computer - download software - from manufacture, input and output format - NMEA
10. Speed - 5 channels, sample - 1 sec., Max K/hr - 1900
11. Plotting
12. Antenna - external
13. Temperature range: -20/80 degrees C
14. Cost - unknown (estimated over $20,000), over five years old

THE FOLLOWING SKETCH (**Figure #17**) SHOWS THE EXISTING COMPONENTS

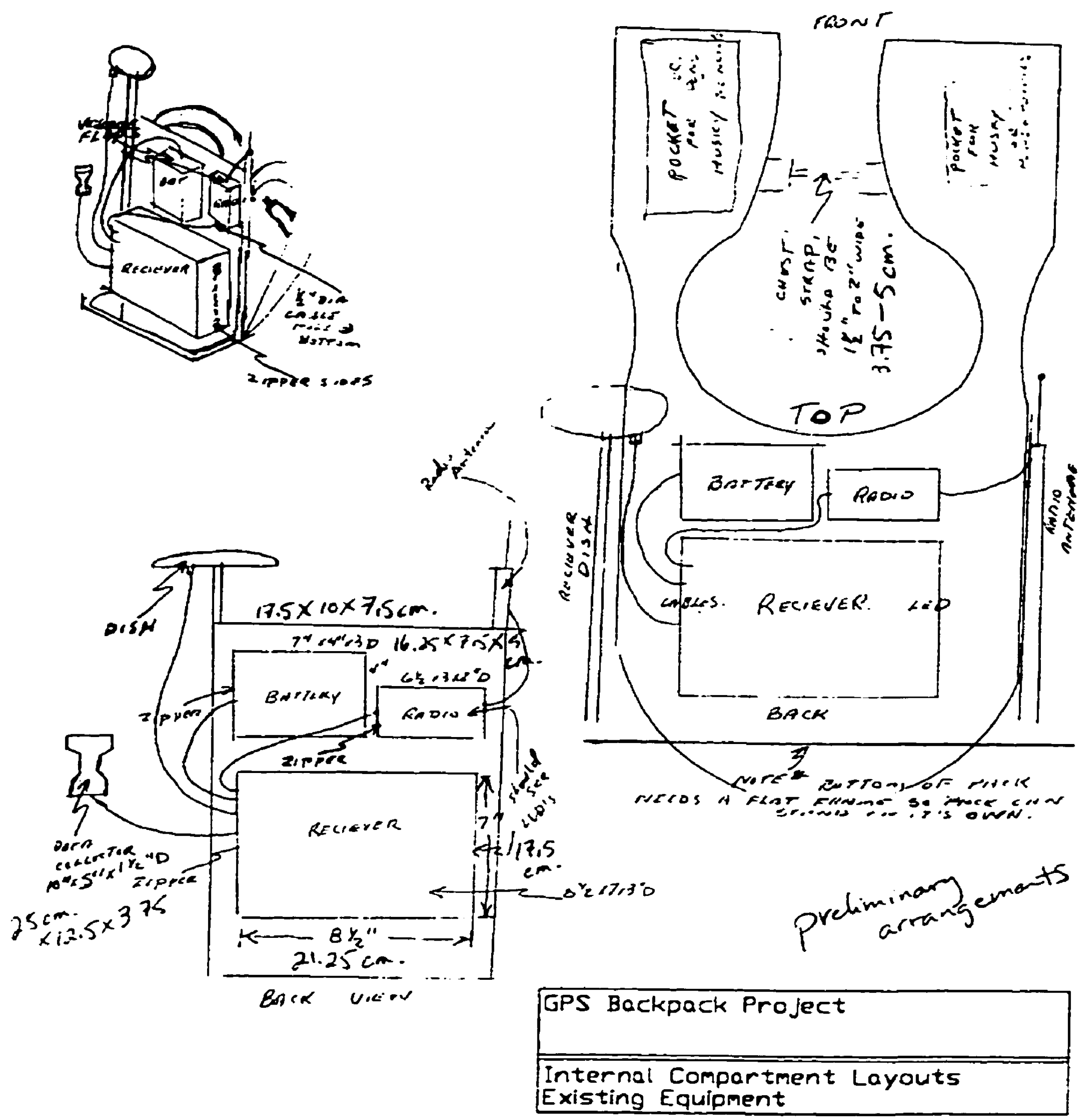


Figure #17 – Existing GPS Equipment

2.2.1 HEALTH CONCERNS WHEN USING GPS EQUIPMENT

Rapid developments in the electronics industry has led to widespread use of radio frequency (RF) devices including telecommunications, radio and television, radar, industrial processing, medical applications and consumer products. Electromagnetic radiation is spread over large areas when generated by communication and radar devices, but only over small areas when used in industrial, medical, and consumer devices. Reflection and scattering of the waves and irradiation by more than one source results in multi non-uniform fields.

Studies of possible hazards to human health from exposure to radio frequency show that there is a need for controls. Exposure to excessive levels of RF over prolonged periods can cause adverse health effects ranging from migraines to nervous system disorders. The type and extent of injury depends on the strength of the field, the exposure duration, frequency, type of modulation, polarization, and distance from the source. Other considerations with respect to this project would be, direction of the beam and whether the whole body or parts of it are exposed. [Workers' Compensation Board of Alberta].

GPS is relatively new and also subject to rapid technological change. Many adverse health effects are not sufficiently recorded. However, documented occupational exposure of RF workers created the establishment of a Health Code outlining maximum exposure levels. The Health Code determines occupational exposure limits which includes: field strengths, contact current limits for occupational exposures, and specific absorption rate limits.

Any information on the current GPS used in the project regarding frequency, field strengths, and power density is not available. Therefore, any concrete data about exposure resulting from the use of the GPS antenna and the radio antenna in combination, is not available. Precautions, then, can only occur by ensuring the following:

1. the antenna beam is directed away from the user
2. the length of exposure time when using the system is reduced
3. a shielding system is developed to block exposure.

These design issues would be for another project. However, for this project, the central health issue is discomfort and injury to the user of the portable GPS and support equipment caused by a badly designed backpack. The goal is to create a better backpack.

3. PROJECT DESCRIPTION

3.1. PROJECT BRIEF

The purpose of this Master's Degree Project is to design a backpack to carry portable GPS equipment for pit mine surveyors. In addition the backpack would maintain the GPS equipment as a complete unit when not in use. The primary material of the backpack for field testing purposes will be Cordura. The final model will be made of a combination of Cordura, coated Packcloth, and other materials such as Neoprene (used for equipment protection). Other materials that satisfy the criteria can be used in constructing the backpack.

An initial list of constraints and criteria provided some direction as design guidelines.

They include:

- **USER** - the back pack will be designed for a very specific group of pit mine surveyors in coal mine industry who perform specific survey activities. The design request was to design for functionality and to also reduce back discomfort.

- **FUNCTION** - the backpack is intended to carry portable GPS equipment used by the company and to support a variety of specific survey work activities.

- **ENVIRONMENT** - the backpack is to be designed to perform in the harsh outdoors environment of pit mining in the coal industry of South Eastern British Columbia, Canada. It must be weather-resistant, waterproof, and be abrasion-resistant to withstand the mechanical rigors of working in the bush.

3.2. SCOPE

The user population included seven males, representing a variety of body sizes. Of the seven males three were full time surveyors while the other four were members of the engineering department that used the GPS backpack and equipment on a part-time basis. Of the three full time employees, in terms of their distribution of both height and weight, the group sat in the 40th percentile of the North American male.

One backpack was designed and made to fit this group specifically since the basis for the project is to design a backpack to carry portable GPS equipment for these coal mine surveyors. When including all seven users, the user group for their height and weight fell in the 80 to 85 percentile of the North American population.

A second backpack with more adjustable features was designed to suit the entire group. The method of analysis with respect to the field testing allows for a collective of individual results. The results determined the final design.

An anthropometric chart was identified and used for reference to ergonomic considerations. In addition, different clothing allowances for seasonal changes were also considered. Further ergonomic investigations took place to understand movement and posture.

Finally, a third concept backpack was constructed that reflected the desires of these users. This backpack is not in actual use due to the fact that it is a concept model. The GPS equipment used for this backpack are a models only and does not have exact resemblance to equipment in use. This only demonstrates what the future could be for the users of this project.

It is noted at this time, the first two backpacks made are the property of Linecreek Mines. They were used in field testing and remain in use at LineCreek Mines.

3.3. ANTHROPOMETRIC DATA

Anthropometric data is obtained from a number of sources which the design is based on. The information was primarily used to determine the size of the backpack needed for the end users. As there is no anthropometric data for a Canadian civilian population, an alternative was needed. Firstly, Stephen Pheasants' Bodyspace British civilian data, extrapolated for the year 2000 closely approximates the Canadian civilian population. Secondly, Human Scale Templates allow for clothing and determine a range for performance. Thirdly, reference is obtained by the Workers' Compensation Board of Alberta. This data is provided in ***Appendix # 6 to # 8***.

4.1. RELATIONSHIP TO EXISTING LITERATURE

Literature published over the past twenty years was surveyed. A number of experts with backgrounds in ergonomics and in kineseology have recorded valuable information from their studies in body mechanics and behavioral aspects of carrying backpacks or related bags and any discomfort from the carrying of loads. The majority of the studies have been directed towards the collection of data for designing backpacks, carrying items on the back (e.g. rifles), and even letter carrier bags.

The literature provides recommended measurements for harness sizes, specific lengths and widths of backpacks for various sizes of individuals, and specific allowances needed for various tasks and body positions, as well as for clothing.

Some key references include:

- BodySpace, by Stephen Pheasant; providing universal data on the "measurement of Man".
- A Biomechanical Comparison of Current Mailbag Designs, by George B. Page, B.S.E., assessing and investigating mailbag comfort for the U.S. Postal Service.
- Vango Vertex Backpack System, by Fraser Warren from King Alfred's College of Higher Education, Winchester, which identifies methods of testing and researching backpacks for the outdoor recreationalist.

4.2. FINDINGS FROM LITERATURE REVIEW

The review of literature is from scientific research and practical applications, and provided the groundwork for the biomechanical aspects of this project. Scientific literature covered the topics of: center of gravity, walking analysis, load carriage, physiological efficiency, and posture. The review was broken down into three categories: backpacks, physiology, and biomechanical.

There are many books, manuals, and magazines on the subject of backpacking and hiking. The authors do discuss proper selection and fit of a backpack and the organization of the contents within the backpack. The major purpose is to carry loads into areas inaccessible by vehicles. It is also noted in some articles that load weight, load position, and the incline gradient of the surface effect the parameters of locomotion. With many manufacturers of backpacks, the description of the packs use and materials are all that is provided. There is very little information of the development of the backpack and even fewer significant research data on load carriage and biomechanical aspects.

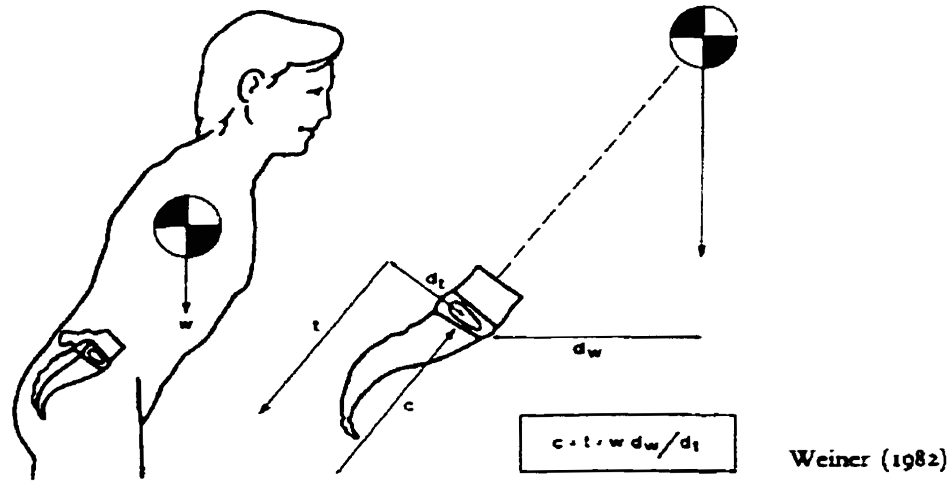


Figure 8.1. Biomechanical analysis of postural stress in a forward leaning position. Note that this analysis ignores the direct effect of the weight of the trunk which the spine must support even when $d_w = 0$.
w is weight of that part of the body above the lumbo-sacral joint; c is the compressive force acting along the axis of the spine; t is the tension in the back muscles (erector spinae).

Figure #18 – Postural Stress

One study of the effects of backpack load, load position, and different incline gradients on the human body during free speed walking (Low, 1988), suggested that the load and its position may contribute to significant changes in some of the segmented body angles, which can lead to undue stress in the low back area. **Figure #18** (Pheasant, 1996, p.149) demonstrates the compressive forces exerted on the back even without a load. Our North American method of carrying/backpacking seems to affect knee flexor and extensor muscles whereas methods used by Nepalese Sherpas affects shoulder elevator muscles. The added stress of immobilizing the trunk while carrying a load, or a pull from the load in any direction increases the amount of energy required to do the work. This information is useful for designing a backpack, in that you would not want to add more work by restricting the shoulder, spine, and pelvis movement (which affect the lower limbs). **Figure #19** demonstrates the effect of speed, energy, and immobilization.

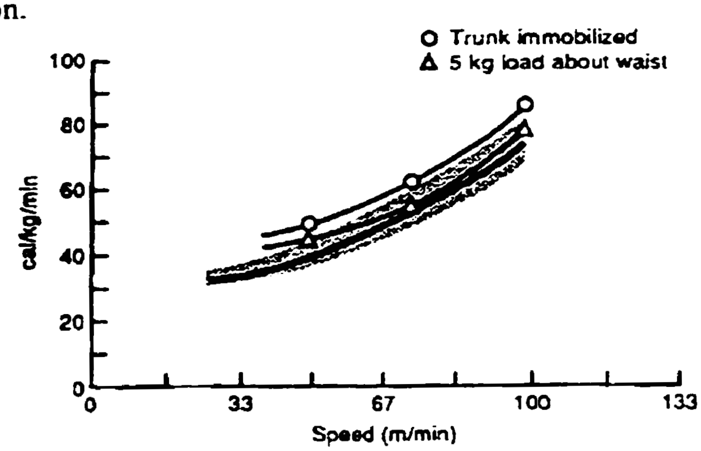


Figure #19 – Speed and Energy Expenditure (Rose & Gamble, p.63)

Estimates of E_w (cal/kg/min) and E_m (cal/kg/m) at Various Speeds and Grades*

Grade		40 m/min		60 m/min		80 m/min		100 m/min		120 m/min	
%	Degrees	E_w	E_m	E_w	E_m	E_w	E_m	E_w	E_m	E_w	E_m
−40	−21.8	54	1.35	70	1.17	85	1.06	98	0.98	106	0.88
−35	−19.3	47	1.18	60	1.00	72	0.90	84	0.84	93	0.78
−30	−16.7	46	1.15	56	0.93	67	0.84	79	0.79	90	0.75
−25	−14.0	44	1.10	53	0.88	63	0.79	74	0.74	87	0.73
−20	−11.3	41	1.03	46	0.77	53	0.66	63	0.63	77	0.64
−15	−8.5	33	0.83	37	0.62	44	0.55	54	0.54	69	0.58
−10	−5.7	30	0.75	35	0.58	43	0.54	54	0.54	70	0.58
−5	−2.9	32	0.80	38	0.63	48	0.60	61	0.61	82	0.68
0	0	41	1.03	49	0.82	62	0.78	81	0.81	110	0.92
5	2.9	59	1.48	74	1.23	95	1.19	125	1.25	167	1.39
10	5.7	69	1.73	93	1.55	121	1.51	155	1.55	193	1.61
15	8.5	82	2.05	114	1.90	150	1.88	187	1.87		
20	11.3	98	2.45	140	2.33	185	2.31				
25	14.0	114	2.85	170	2.83						
30	16.7	133	3.33	204	3.40						
35	19.3	153	3.83								
40	21.8	174	4.35								

*Modified from Ref 39.

Table #1 – Speed, Gradient, and Energy Expenditure (Rose & Gamble, p.62)

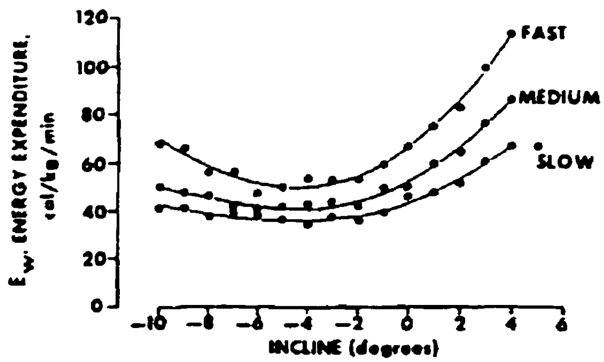
A U.S. military study (Clarke & Mathews, 1955), found that the military combat pack carried high affected the neck extensors, trunk extensors, and shoulder elevators. The U. S. military studies found that walking speed has a greater effect on energy expenditure than increasing the weight of the load. **Table #1** (Rose & Gamble, 1994, p.62) demonstrates the effect of speed and increase of energy expenditure. The study concluded by stating the following principles for ideal load carriage:

- the load should be distributed over a wide area
- the weight of the knapsack should be balanced by weight in front
- all loads should lie as close to the body as possible
- no compression or armpits or chest by shoulder straps should occur
- total load should not exceed 45 pounds.

Most research definitely proves that load position and incline gradient affects performance. **Figure #20** demonstrates the increase of energy expenditure with changes in grade. Studies find that an even load distribution on the torso and midway is the best position. Other research has found that if the load is positioned on the torso by means of a padded hip belt, there is less forward shift (Low, 1988). The more significant findings are:

- a high placement of the pack tends to destabilize tall men, so tall men prefer to carry loads lower
- to counterbalance the pack, the body leans forward without significant realignment of other body segments
- head and shoulders move forward in an effort to balancc the load resting on theback.

Despite technological advances, manual load carrying to perform tasks is a form of man-powered transportation that is still an indispensable resource for many occupational tasks. While it is difficult to assess the incidence of injury associated with load bearing, there is also insufficient data to justify concern for those who are involved in this type of activity. What this shows is that there is very little meaningful information about injury prevention. There are other studies that examine other devices such as yokes, head carriers, forehead straps, and even dragging.



Effect of grade on energy expenditure of a normal young male while walking at three speeds.

Figure #20 – Effect of Gradient and Energy Expenditure (Rose & Gamble, p.62)

One other significant study (Kinoshita, 1982), states that the optimal weight of the load for a physically fit backpacker is 30% of their body weight. He also states that a two-pack or double pack system was shown to be biomechanically superior to a backpack system. To understand the mechanics of the body, it was useful to refer to the skeletal structure as in **Figure #21**(Craik & Oatis, 1995, p.160).

Also:

- carrying loads of 20-40% affects non-trained individuals and results in changes in biomechanics; 20% is a safe load for non-conditioned carriers
- heavy loads affect posture and gait patterns and increase stress related injuries wih a heavy load over time increasing the magnitude of damage
- double packs promote a more normal walking position and gait than a single pack or a conventional system.

skeletal body structure From: Gosling JA et al: *Human Anatomy*. 2d ed., 1990

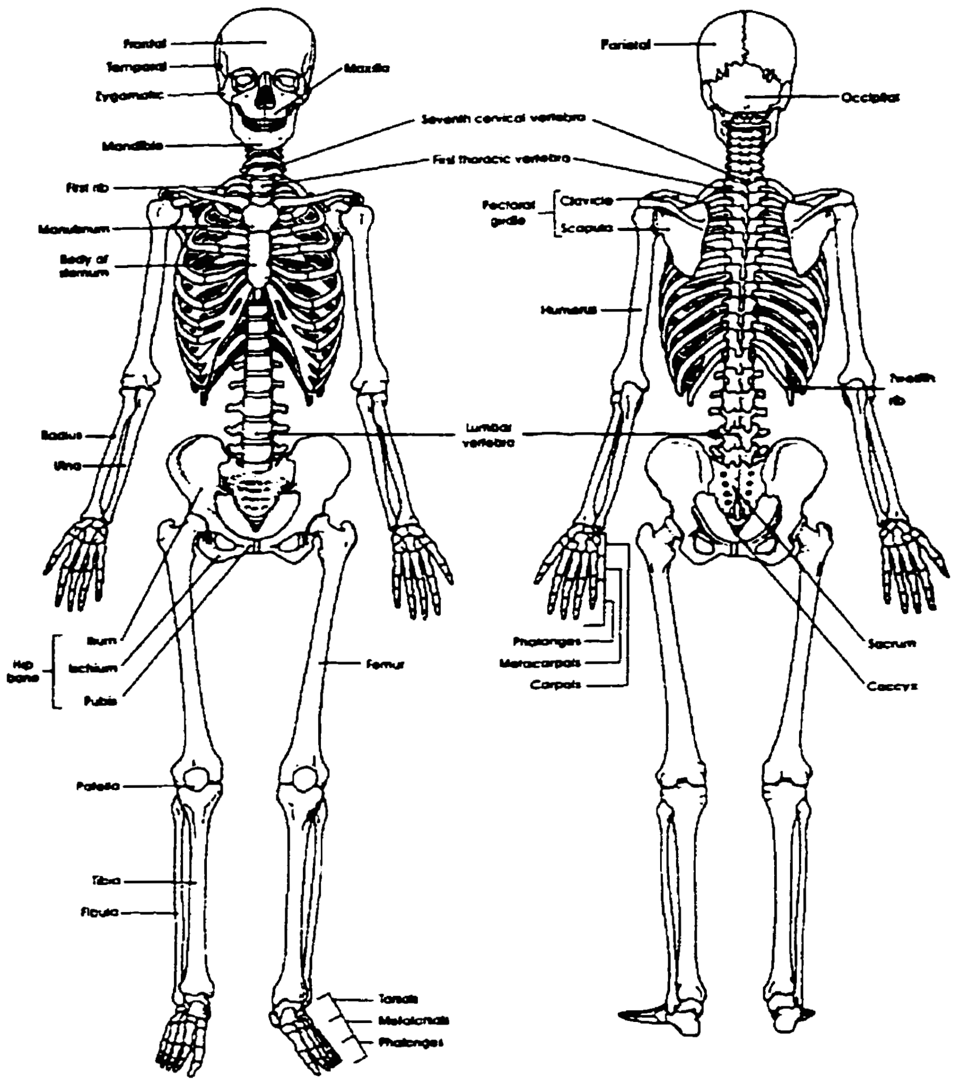


Figure #21 – Human Skeleton

The only other interesting piece of information pertains to a study (Kamon, Metz, Belding, Pandolf, 1973), where it stated that environmental conditions also affect a person carrying loads. Altitude, temperature, and ground composition add to the metabolic cost of carrying loads. **Figure #22** describes a field situation, where there is an attempt to take into consideration all aspects of energy expenditure during one day of work activity.

It is also important to add, gait analysis information is generally obtained for the purpose of prosthetic development. With modern techniques in surgical hip replacement, knee and shoulder surgery, movement analysis was necessary. Physiotherapists use gait analysis for correctional therapy on patients where deviations are compared to normal walking. An example of gait analysis and an institutional form is **Figure #23** as well as a description of gait phases in **Figure #24** (Rose & Gamble, 1994, p.142), shows what type of information is collected. Medical procedures are created to have patients reach normal locomotion based on theory and normative data. Medical studies rarely deal with carrying loads, yet the study of biomechanics is an important basis for research dealing with carrying loads.

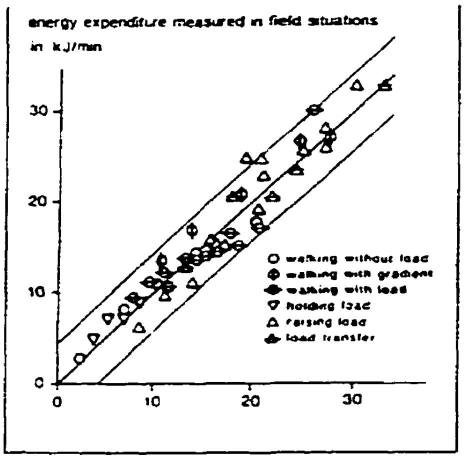


Figure #22 – Energy Expenditure in a Field Situation (Rose & Gamble, p.112)

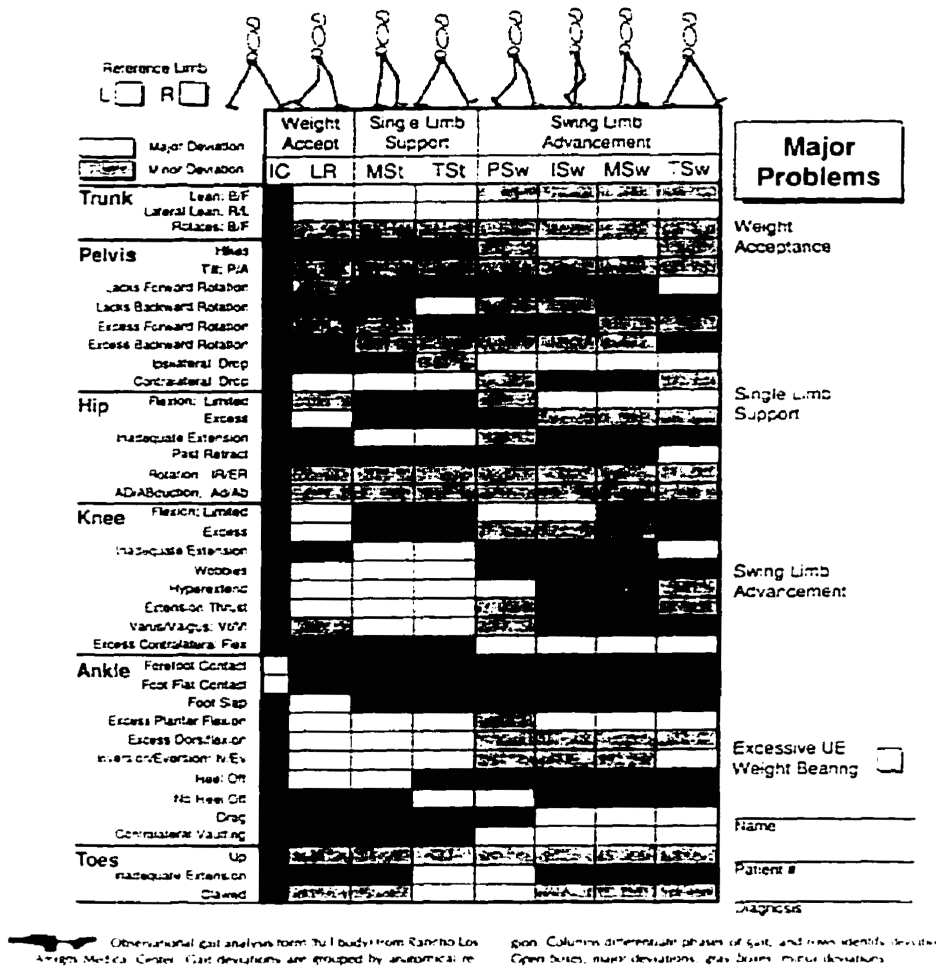


Figure #23 – Medical Evaluation of Mobility (Craik, p.116)

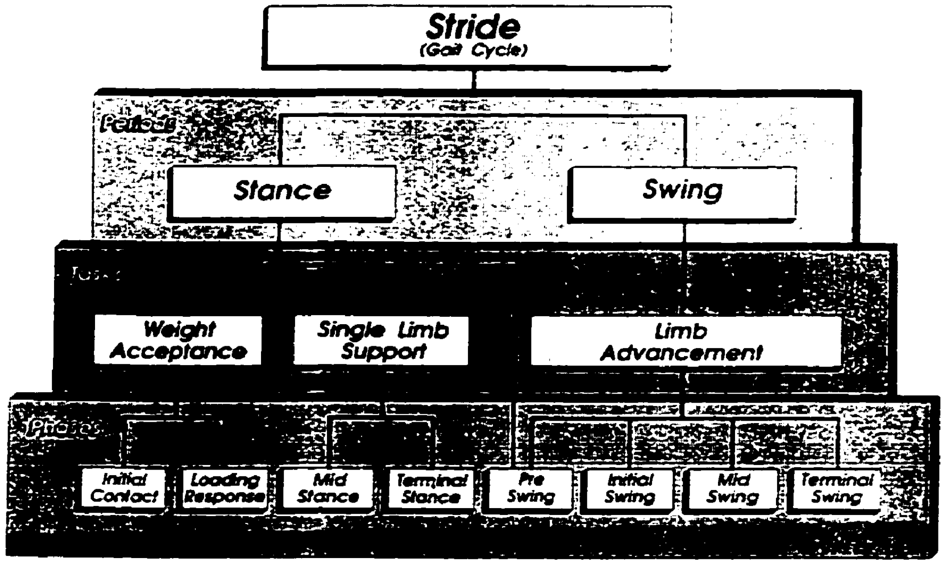


Figure #24 – Phases of Walking (Rose & Gamble, p.142)

4.3. ERGONOMIC CONSIDERATIONS

A number of ergonomic considerations were investigated:

- dimensions (human, backpack, equipment),
- determining field testing,
- analysis of anatomical movement (how we walk) which also includes posture,
- other relevant findings from the task analysis.

4.3.1 DIMENSIONS

Allowances were made for clothing, access to equipment, the size of the user, and for movement specific to work activities. ***Appendix #6, #7, and #8*** were used as sources of reference.

- **TRIALS** - The limiting factors of the design to be field tested were determined by having two different models for the users to try. Each model was differentiated by the features it had or didn't have. Responses from the users in the field test, identified which design details detract from or contribute to optimum performance.

- **ANATOMICAL MOVEMENT ANALYSIS** - During walking, upper body weight is transmitted through the pelvis to the legs. The pelvis is built for strength and backpack design normally addresses this. Posture is monitored in task analysis as a relationship exists between the user and the equipment.

4.4. POSTURE

The following sections on Posture, Center of Gravity, and Balance are closely related. For ease of explanation, they are treated separately. These sections are adapted from Human Walking, Rose & Gamble (1994), Baltimore: Williams & Wilkins, pages 62, 63, 142, 143.

Posture is defined as the relative orientation of the parts of the body in space. To maintain such an orientation over a period of time, muscles must be used to counteract any external forces acting on the body. The force that affects all external forces is gravity. (Pheasant, 1996, page 148).

Posture is also a position a person adapts to perform a particular task. The position in this project refers to the relationship between the surveyor and the added dimension of wearing a backpack loaded with equipment. The extent to which posture is constrained is dependent upon the nature of the connection between the two. If the dimensional match of the connection with the backpack is inappropriate, the short-term and long-term consequence for the well-being of the person can be severe.

It was found in the task analysis that the average position of the surveyors while carrying the backpacks, was a forward lean of 10 degrees of more. Because of gravity and the position adopted, a significant amount of work is needed by the back muscles and hip extensor muscles to carry the load. The angle of the hip and lumbosacral joints also create a "postural stress" (Pheasant, 1996, page 149). The best working position is one where there is the least amount of postural stress. The field test models and the final design reduces postural stress.

An indication of discomfort was expressed from prolonged wearing of the backpack by one surveyor. Although this seems vague, this discomfort can be the prologue to nagging back pain where relief could only occur with a change of position or the removal of the backpack. In the survey questionnaire, this was also indicated as that individual's solution to dealing with back discomfort. Upon searching for the definition of back discomfort, medical literature refers to discomfort where "comfort is typically assessed by the absence of discomfort". No references are available for this definition - you either have some discomfort or pain, or not.

Age affects posture by changes in the lower limbs and in the hips. In early stages of old age, body weight generally increases. The increase of weight causes more strain on a weakening musculature and the legs. Maintaining working postures becomes increasingly difficult. Both age and weight were factors to be considered in the design investigation.

Muscular tension particularly in the neck, shoulders and back, may also be associated with psychological stress and, since work activities performed in poor postures may also be frustrating in other respects, the effects may be interrelated. Some people are more "tense" than others in these situations and personality differences may be of some importance in this respect. Even in the short-term, people vary greatly in their tolerance to postural stress.

4.5. CENTER OF GRAVITY

The concept of a "center of gravity" is useful in dealing with carrying loads and stability for the body structure. Although the force of gravity pulls downward on all parts of the body and on all objects that the body is carrying, it is possible to locate a particular point where balance will be achieved. When loads are applied equally or in a symmetrical fashion, they will be acting along a vertical line which passes through the center of gravity. The most common problem for backpack users, is that the shape imposes a load that creates instability. The load is not distributed properly as it sits on the back. This could be caused by uneven distribution of weight inside the pack or how it disproportionately protrudes from the back.

In the task analysis, this was demonstrated with the old backpack. The users had to lean more than 10 degrees forward to obtain balance and fight the forces of gravity on the backpack. The load of the antennas was high and also caused some compressive stress on the back. A lack of proper backpack adjustments also caused some load carrying compensation which could be observed in the awkward walking positions.

4.6. BALANCE

Carrying a heavy load is a necessity when working with portable GPS units of high accuracy. Specific body strains when carrying a load with any form of harness mechanism, include pressure or abrasion from the straps and from the load, and muscular and spinal strain caused by weight.

Figure #25 – Balance

The result is an increase in heart rate and oxygen consumption. Gravity and other forces act on the load in every direction with every movement and step making balance difficult. **Figure #25** demonstrates that balance is best achieved when the spine is straight, and in a position where there is the least amount of forces acting on the load. Effective pack/bag design can counter and reduce these forces, providing greater comfort when carrying large loads. A well thought out system will help maintain balance and mobility in variable terrain, and lower the amount of effort needed.

The two essential considerations of a pack/bag design are: a) how it is attached to the body and b) the pack/bag itself.

The backpack must work in the following ways:
1. allows the body to maintain an erect posture
2. follows the body's complex movements
3. remains stable, and
4. be adaptable to individual back/anatomical shapes and sizes.

These points are the basis for the design criteria.

4.7. MOVEMENT

When walking, the torso moves a different direction than the legs. The load bearing surface of the back and shoulders also moves independently of the other load bearing surfaces, i.e. hips and buttocks. In addition, the back actually changes shape and size with each step. The body leans backwards and forwards with each step. When leaning forward, the lower back stretches over 1 cm. before it relaxes and returns to its normal length. The body sways from side to side with each double step. As it leans to the supporting side the torso compresses, while on the stepping side it extends. The hips swing with the legs, but the torso and arms rotate in the opposite direction to maintain balance (Clarke & Oatis, 1995).

When walking on uneven terrain, the same basic movements occur, but in differing degrees. Back extension increases when stepping upward. The further the forward lean, the longer the back becomes.

Walking faster increases hip swing, causing the back to swing more in the opposite direction. If the load being carried does not flow with the body, movement is a struggle. At best, struggle causes discomfort, and can lead to injury.

4.8. ANALYSIS OF RESULTS

Seven subjects participated in the interviews, survey and task analysis. It was determined that there may be an acceptable backpack design suitable for the specific anthropometric characteristics of the group.

Videos from the task analysis, showed poor posture occurring in the head/neck, and upper/lower back regions when wearing the current backpack. These are the body regions commonly affected by poor backpack fit. There was little indication of poor shoulder posture because the subjects found it acceptable to adjust the shoulder straps.

There are several factors causing the poor posture:

1. a lack of adjustable features in the old backpack style
2. uncomfortable hip belts or failure to use the hip belt at all
3. insubstantial features to support the activities of pit mine surveying.

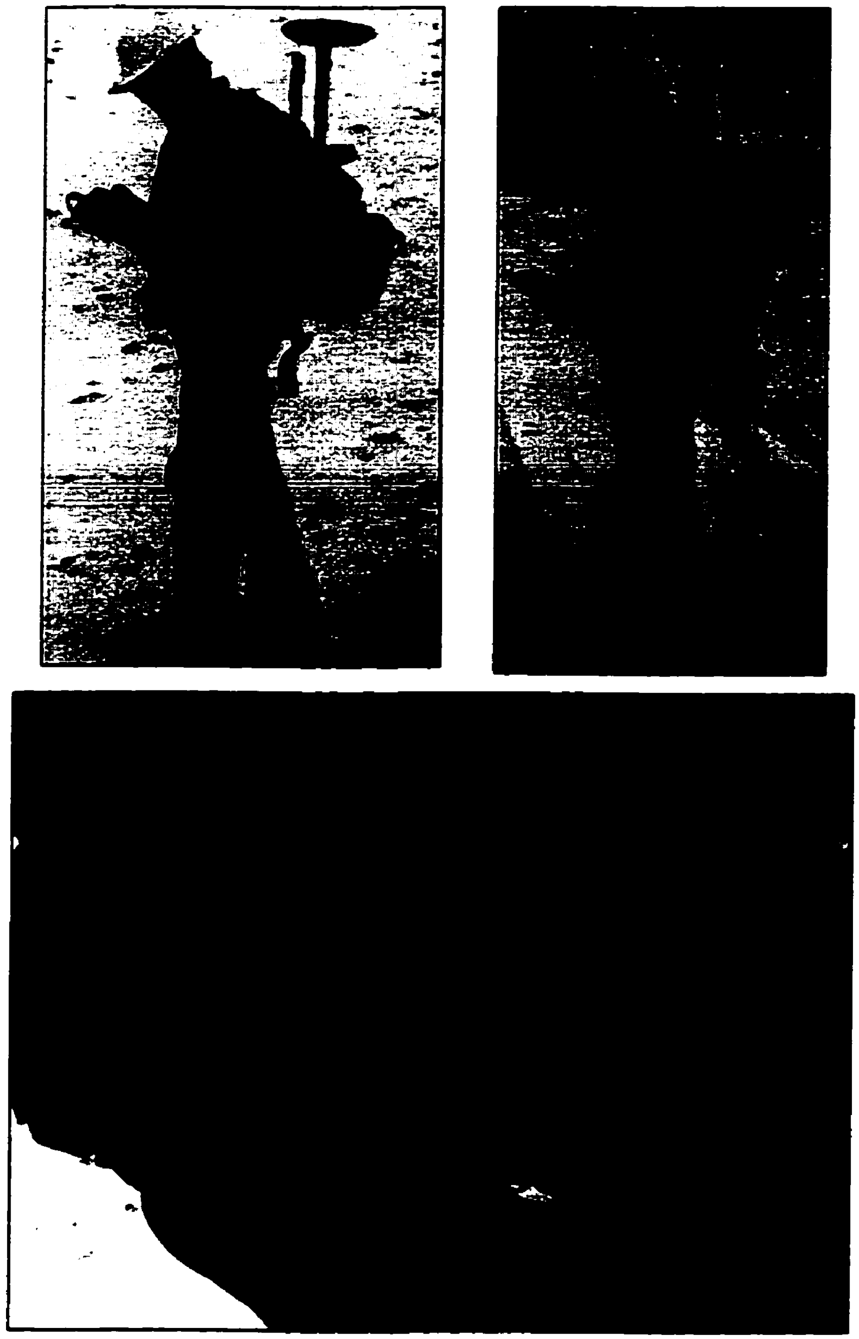


Figure 29 – Problem Areas Identified

Six of the subjects stated they rarely adjusted the backpacks when they wore them because the few possible adjustments were too awkward. The reasons cited for not adjusting, ranged from the size of the buckles, to the width of the straps. The result of the difficulty in making adjustments or the limited potential for adjusting, negatively impacts the user's comfort.

All of the pit mine surveyors use a variety of other equipment to support their work activity. For example when drill patterns are staked out for blasting, up to 100 stakes per day could require positioning. In addition to their the GPS equipment, the surveyors would have to also carry: wooden stakes (2.5x5.0x45.0cm.), a hammer, spray gun stick markers, cans of spray paint, possibly rolls of plastic survey tape, and numerous felt pen markers. The carrying of all these other items plus the GPS equipment is cumbersome while performing the work activities.

After collecting the task analysis data, it became evident that the two areas of design focus would be cable management and creating a better distribution of weight with the equipment. The equipment sits loosely in the backpack and entwined with cables. The surveyors saw little use in closing the zippers because they needed to check the equipment LED's. There appeared to be an excess of cables contributing to the weight of the system. When the surveyors wore the pack, the pack sat too low causing pressure in the lower back region. The design of the pack was such that it projected out and away from the back allowing the pull of gravity to create more work than necessary to carry the pack. **Figure #29** demonstrates the cable management and weight distribution problem.

Designing for these specific users is largely problem solving with attention on user needs. LineCreek Mines initially identified the problem of discomfort while the surveyors wore the backpack. At an early stage of the research (task analysis), it was discovered that there were other issues which should receive attention (cable management and organization of equipment). The focus was to determine some solutions and implement those solutions. Social Scientists and Practitioner-Researchers commonly refer to this approach as "action research".

4.9. RESEARCH AND NEW PRODUCT DEVELOPMENT

Research and new product development is ongoing with GPS equipment. Most of the focus is on the technology with much less of a focus on the end user. Current systems treat the bag systems for the equipment as packaging. Most systems are also designed as if the users are doing the same type of survey work on flat terrain, with access to a vehicle nearby, and in a clean environment.

Currently, ideas for new product development are obtained at trade shows for those wanting to purchase GPS equipment. The emphasis is mostly on sales with little regard for adapting the equipment to different end user markets; the exception, is setting up computer programs for the information.

4.10. MARKET INFLUENCES

The object of this project was to design a backpack that will satisfy a predetermined market segment and a specific user group. This backpack demonstrates a potential application to a greater range of products.

Backpacks are classified as utilitarian. Also, backpacks can portray a variety of shapes for all purposes, sustain and exhibit theories of balance and support, contain decorative features, and demonstrate the range of possible new materials.

As a general observation, backpacks represent current trends in evolving material technology and fashion.

The changes in backpacks over the years have been gradual, but with an emphasis on reducing weight. Weight reduction is achieved by using plastics for buckles, sliders, and zippers instead of metals. Lighter and tougher fabrics are used rather than heavy canvas.

4.11. USING A FOCUS GROUP TO FACILITATE PRELIMINARY DESIGN CONCEPTS

A focus group was conducted to evaluate current portable GPS carrying systems and to also establish a control group for information. Nine subjects participated in the focus group which involved evaluating study models. The evaluation included perceived physiological stress (estimated work and exertion), perceived musculoskeletal stress (body part discomfort and postural deviations), and functionality (aspects of usability).

A system of study models was constructed using multiple pouches and padded straps with Velcro attachments. The purpose was to have participants construct various combinations using the segments and to manipulate them with the Velcro. Each combination of segments offered improvements and suggested possible solutions.

Overall, to gain acceptance by the focus group, it is clear that any new design concept must address key functional requirements while endeavoring to improve efficiency and comfort. A number of suggested improvements were recorded. Each design improvement had potential. The challenge is to integrate all of the suggestions into one design concept.

Figure #26 and #27 are examples of possible arrangements the focus group identified.

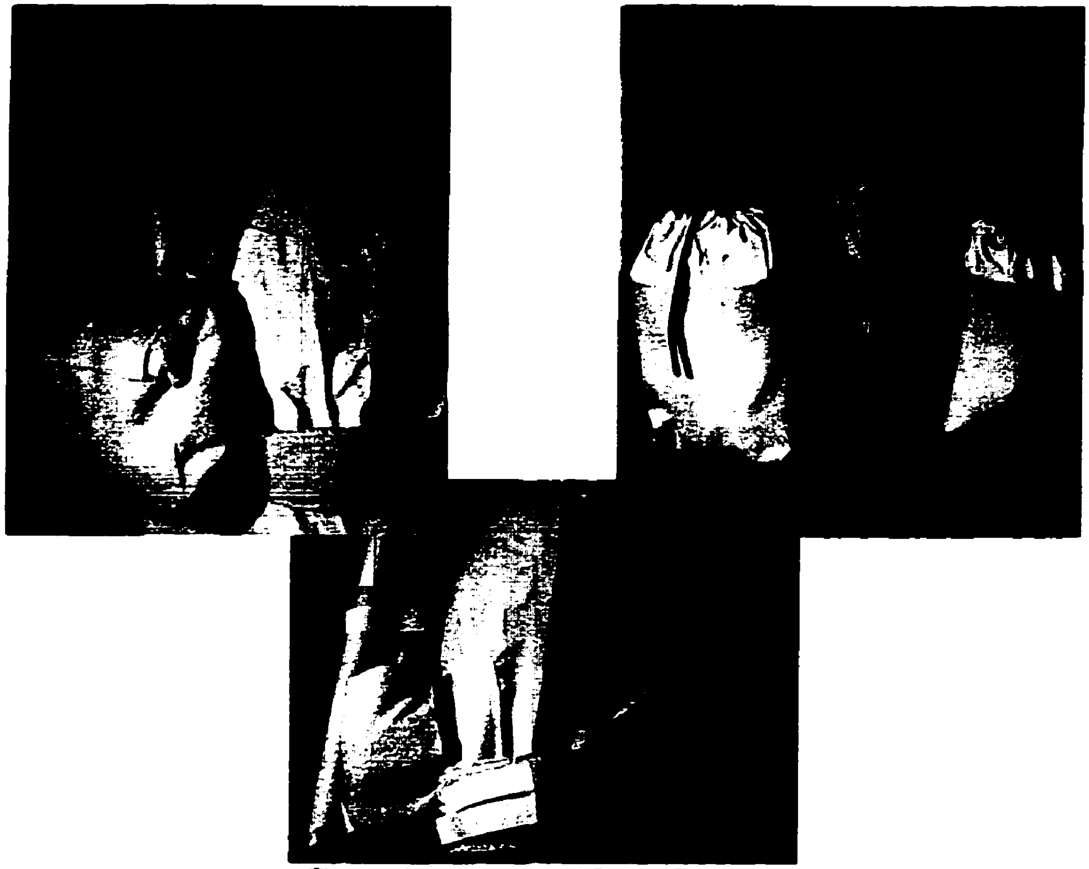


Figure #26 – Pocket and Pouch Placement

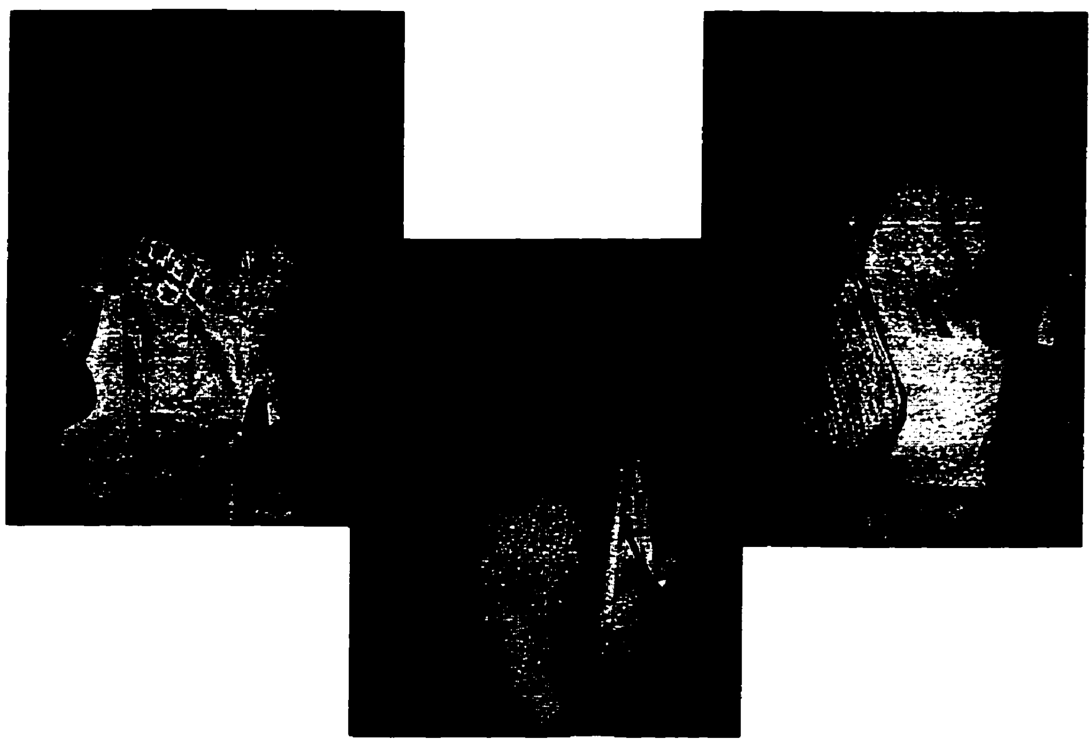


Figure #27 – Strap Arrangement

4.11.1. FOCUS GROUP RESULTS

1. Gender - 8 males and 1 female (nine out of twelve attended).

2. Average age - 35 to 45 yr. old.

3. Position - 7 full time surveyors; 1 engineer; 1 industrial manufacturer.

4. Work areas - small private companies.

5. Average years of work related to surveying - over 10 years.

6. Average hours that the surveyors carry GPS equipment - 6 to 8 hours/day.

7. Average hours in one week that the surveyors carry GPS equipment - 30 hours.

8. Most use assigned equipment exclusive to them but will use rental equipment or other equipment when their equipment needs repair.

9. Most will initially spend time to adjust equipment to suit their needs and then leave it.

10. Those who use equipment that is five or more years older complained that the equipment is too heavy and bulky and didn't enjoy using the equipment.

11. The equipment is too top heavy because of the antennae.

12. Only two complaints of lower back discomfort. The reason stated was because of their age; the back discomfort is relieved by taking off the backpack for short periods of time.

13. Those experiencing back discomfort, state Tylenol relieves the pain and didn't need medical attention at this time.

14. All participants described their fitness level as average.

15. Active discussion lead to numerous suggestions for backpack improvements:
    - include a data collector pocket
    - if a frame is used, use a curved frame
    - frameless packs are preferred because they are lighter
    - chest packs not recommended because of a "squashed feeling" from compression
    - a vest/pack would have to be close fitting
    - a vest itself is hard to distribute weight evenly
    - preferred to keep 60-70% of the load on the hips

- function and fit is a higher priority than a pack that can stand on its own
- a fully padded back panel means more comfort and a better "carry"
- A wider shoulder strap stabilizes the load
- wider chest straps and hip belts reduce lateral sway
- safety features of a highly visible color and reflective tape preferred
- buckles are easier to use for adjusting
- "S" shaped shoulder straps are more comfortable, but may not fit everyone
- high cut hip pads are more stable
- a dense foam padding is more firm and responsive and longer lived
- pole pockets combined with the main bag of the pack is more stable
- stackable internal pouches make it easier to distribute weight
- a clear view of equipment LED's (light emitting diode) without going into the pack to check on equipment
- it is preferred to have cables run inside the pouches without having to open zippers
- bound seams prevent water leakage and increases strength of pack
- shape pack to body to decrease backward pull and snagging on foliage
- reinforce base and straps where roughest treatment occurs
- prefer only one pouch as an entire compartment rather than two or more separate pouches
- a "hip shelf" in the hip belt would help the pack rest on the hips better
- a polyester/cotton thread is stronger and thread expands when wet to seal the seams
- an abrasion resistant material is preferred; most people are familiar with cordura - a 1000 denier cordura makes the pack water resistant to pressure of 800mm.

4.12. TASK ANALYSIS - METHODOLOGY

Task evaluation was completed by survey questionnaires and observation at the worksite (including photos and videotape). These methods were used to identify pertinent information and required data transfer, coding, and evaluation.

POSTURE AND ACTIVITY

Observation of workers at the worksite is the main source of relevant data. A work site ergonomic study of the surveyors identified strain, as expressed in their postures, and revealed the need for a more convenient method of carrying the antenna.

As an observer, a visual task allocation problem occurred. Initially the periodic time cue was set at one minute. In order to make observations, record them on a tally sheet, and maintain personal safety in the field with the surveyors, an adjustment was required. To accommodate the need for greater freedom in observation time and less visual demand for data entry, the periodic time cue was extended to every ten minutes for more convenient data collection.

A pictogram sheet, as in **Figure #28**, was also developed to describe activities specific to the surveying task. To enter the data, as observed, the selected activity was marked with a check mark under the corresponding pictogram. The data was then documented quantitatively and overall observations of activities were calculated hourly.

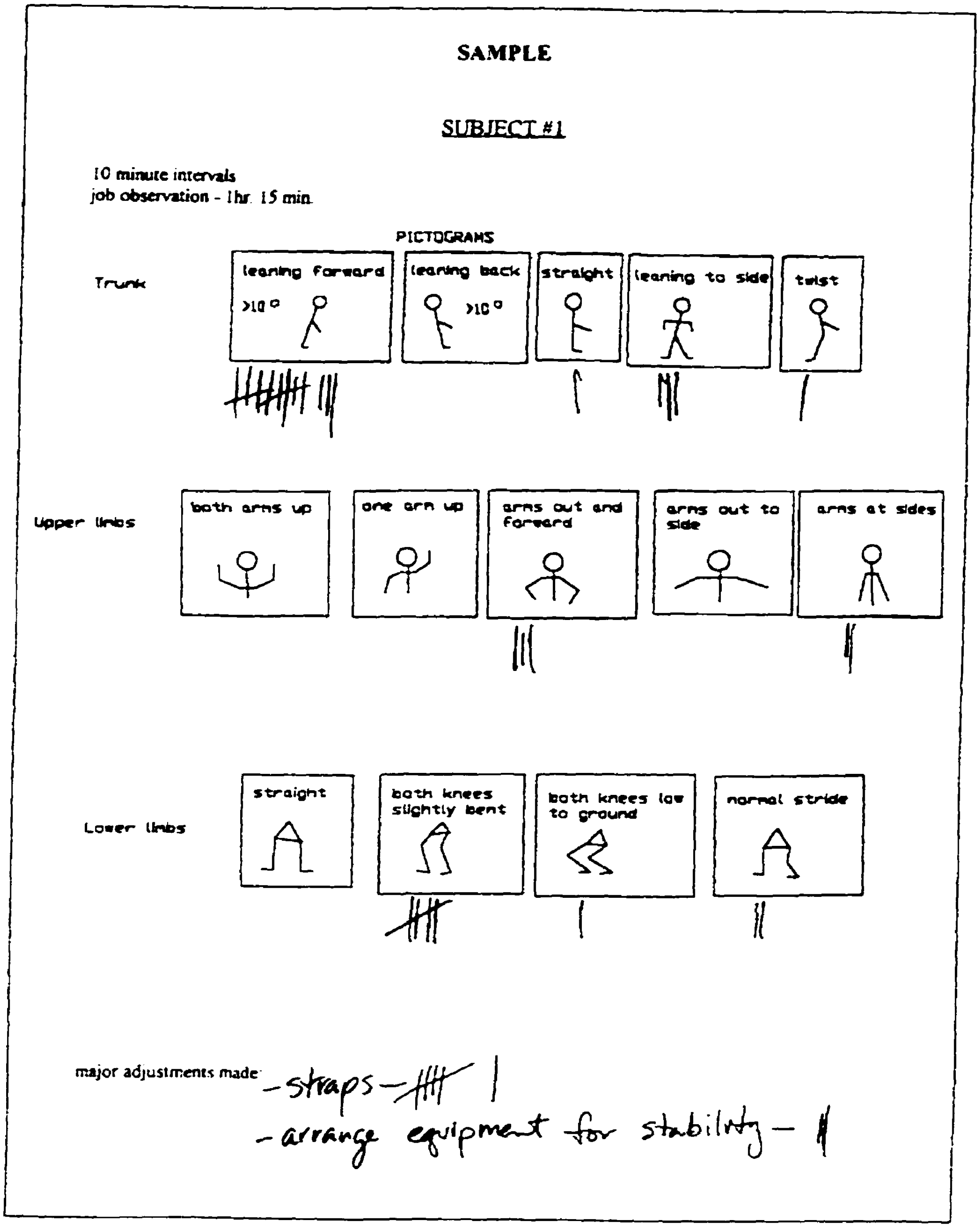


Figure 28 – Pictogram

Also noted was the amount of time applied to:

- accessing backpack
- adjusting backpack
- work interruptions by existing equipment system (e.g. having to put the data collector down to mark stakes and hammer them into the ground. It should be noted that while the data collector is an important part of the GPS system, in most cases there is no where to conveniently store it.)

RE: BACK PAIN

Back pain, as a typical indicator of health hazards in industry, has always been a challenge. Limitations on loads to be lifted and carried seem to be an effective tool to decrease the probability of circulatory or biomechanical hazards.

During observations, employees were asked to indicate when they felt the backpack should be taken off, how long they were comfortable wearing it, and how long of a break there should be, between periods of wearing the backpack.

4.12.1. ANALYSIS OF RESULTS

Seven subjects participated in the task analysis. It was determined that there may be an acceptable backpack design suitable for the specific anthropometric characteristics of the group.

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There are several factors causing the poor posture.

- a lack of adjustable features in the old backpack style
- uncomfortable hip belts or failure to use the hip belt at all
- insubstantial features to support the activities of pit mine surveying.

Six of the subjects stated they rarely adjusted the backpacks when they wore them because the few possible adjustments were too awkward. The reasons cited for not adjusting, ranged from the size of the buckles, to the width of the straps. The result of the difficulty in making adjustments or the limited potential for adjusting, negatively impacts the users comfort.

4.12.2. SURVEY RESULTS

Please refer to ***Appendix #4*** for the questions asked in the survey.

1. Gender - male; five in total - all responded.
2. Age range - 40 to 50 years.
3. Job position - either full time surveyor, or geology technician participating in survey activities, or mining engineer.
4. Work area - work for or under an engineering department.
5. Average years of survey work - over 15 years.
6. Average hours in one shift that the GPS backpack equipment is carried - 4 to 5 hours.
7. Average hours in one week that the GPS backpack equipment is carried - 20 hours.
8. Time spent sharing or changing equipment - weekly. Equipment is not assigned to each worker exclusively; better equipment goes to senior person.
9. Time spent adjusting backpack to suit needs - none. Only one person stated they adjust the chest straps.
10. Amount of back discomfort - only one person indicated mild problems; this person mailed the survey form to me. All others said none. These forms were given to me by the Health and Safety Officer.
11. Area of back discomfort - lower back and between the shoulder blades; both sides.
12. Length of time of discomfort - no specific time indicated; discomfort may or may not persist after the discontinuation of wearing the backpack.
13. Modification of job due to discomfort - of the mentioned discomfort, some modification occurred because of the symptoms; no indication of what that was.
14. Medical treatment for discomfort - none.
15. Fitness levels of participants - described themselves as average.
16. Suggestions for improvement include: pocket for data collector, access for
17. inspecting/connecting cables, ability to read LED's (light emitting diode), easier adjustment for straps, and larger buckles and straps.

4.13. INVESTIGATION OBJECTIVES OF FIELD TESTING

1. To gain design information
2. To ascertain portable GPS equipment users' perceptions regarding:
   (a)the current carrying systems already in place, and
   (b) the expectations of potential carrying systems before they are utilized in the future.

The overall objective is to gain as much information as possible in order to develop a design concept which, if implemented, will eliminate and/or minimize the pit mine surveyors' problems regarding health, safety, and performance considerations associated with their work activities.

4.13.1. GOALS OF FIELD TESTING

The field testing was specific with regard to selection of users, and with the use of a post field test survey. Please refer to ***Appendix #12*** for the post field test survey questions.

Its aims are:

- to evaluate (from each users perspective) the overall success of each backpack model
- to evaluate the success of each backpack with respect to comparison of the "before" and "after" (old pack vs. new pack)
- to explore statistical relationships in the users' responses
- to explore the realism of the users' expectations respecting the practicality of
- future implementation
- to suggest possible improvements in existing or future portable GPS/GIS backpack systems.

4.13.2. FIELD TESTING AND STUDY PROCEDURE

Backpack Model A and Backpack Model B were constructed and field tested for sixteen weeks. The surveyors actually used the backpacks on the job performing regular activities. Survey questionnaires and interviews were developed and administered at the end of sixteen weeks.

It is noted that, at this time, it is questionable whether reliable inferences about other actual or potential backpack designs can be accurately drawn from this specific group. Because of the small sample size, the results obtained suggest certain design criteria only for this group. At this stage, this would be considered as a custom design project. In order for this study and design project to be based on statistical reliability, research and field testing of identical models would have to be conducted using a statistically significant sample size.

A statistically significant sample size may be one where a larger group of surveyors tested the backpack. The purpose would be to obtain a more sensitive test of any difference between the conditions tested and to determine the common preferences in a backpack design for this specific purpose. The only advantage of this would be for mass producing and marketing a more generic backpack. The customizing specifications, however, would be lost if this was the preference.

4.13.3. FIELD TEST RESULTS

1. All agreed that the Prototype Models were more comfortable than the current and previous models used.

2. A suggestion made referred to having the equipment pockets more expandable to accommodate the second set of GPS equipment the mine owned. A solid material for the pockets would prevent the corners of the equipment from getting caught as the equipment is slid into the pocket.

3. As the surveyors used the prototype pack over the summer season, a suggestion is to use a more breathable material.

4. All commented on the pack color. They prefer red, or a red and black combination. Orange made them feel like they were wearing a Personal Floatation Device. The safety factor of using orange was not important to them. A "toning" down of color is recommended.

5. It was stated by an individual that by applying the product ScotchGuard to materials that the coal dust will not penetrate. Further experiments would be needed to test that idea or comment. Materials preferred by the surveyors for the pack are the traditional Cordura and PackCloth.

6. A preference is indicated for the usual hip belt and shoulder strap of a back pack as it is something they are more familiar with.

7. A request was made to have a stiffer back pad.

8. The surveyors prefer a holster type pocket for the Data Collector and hammer. Half indicated wanting the holster on the left, and half wanted the holster on the right side.

5.1 DESIGN PROCESS

The design process took many forms. To aid the process, a visual model was created as a guideline. **Figure #30** shows the visual model used for the design plan. The process actually repeats itself as new information is introduced. Other tools used include check lists which can be referred to in ***Appendix #9 to #13***. These check lists act as reminders of detail not to be missed or addressed.

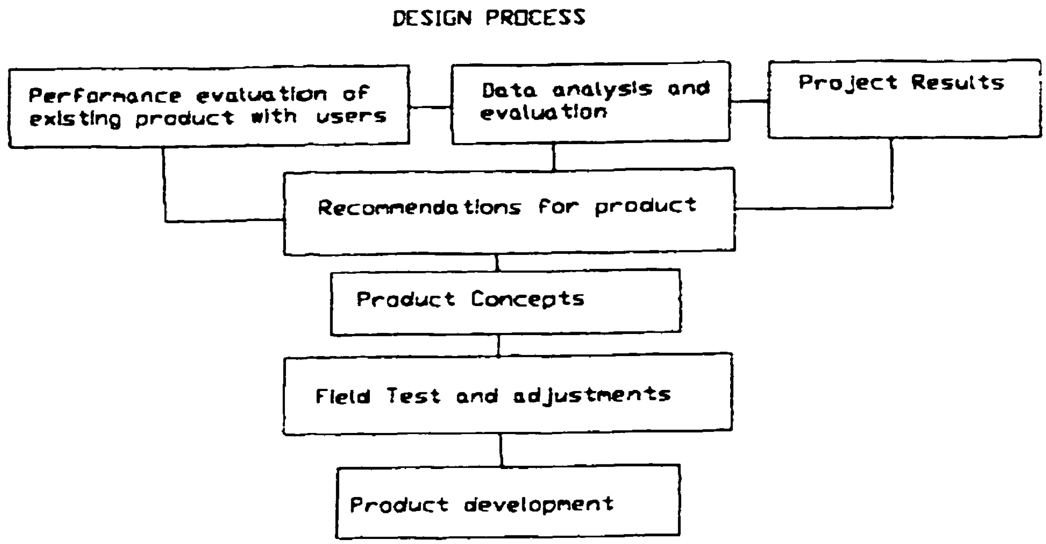


Figure #30 – Design Process

Much of the design work included free sketching, as shown in **Figure #31** and paper modeling. Other work included computer modeling, experimenting with ideas on paper as shown in **Figure #32**, and physically organizing equipment components for practical and visual understanding as shown in **Figures #33** and **#34**. The process attempts to include as many ways as possible to generate ideas and to see the problem from other points of view.

The process started with creating Backpack Concepts using little information. As more information became available, more product ideas were generated. Design constraints were introduced into the design from the research knowledge gained, and Prototype Models were constructed. Further refinement of the design occurred after the Field Test, resulting in the Final Backpack design.

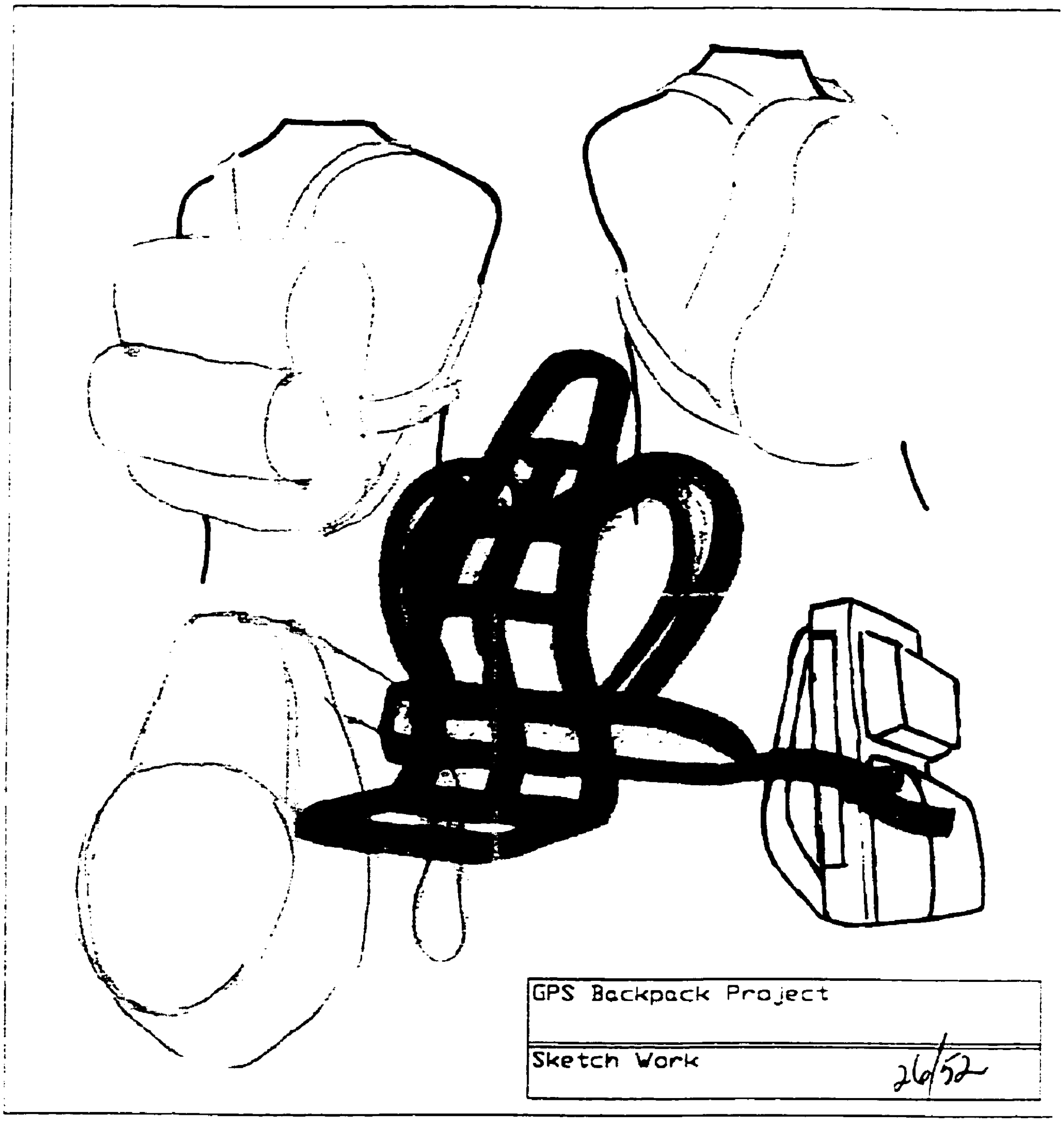


Figure #31 – Freehand Sketch Work

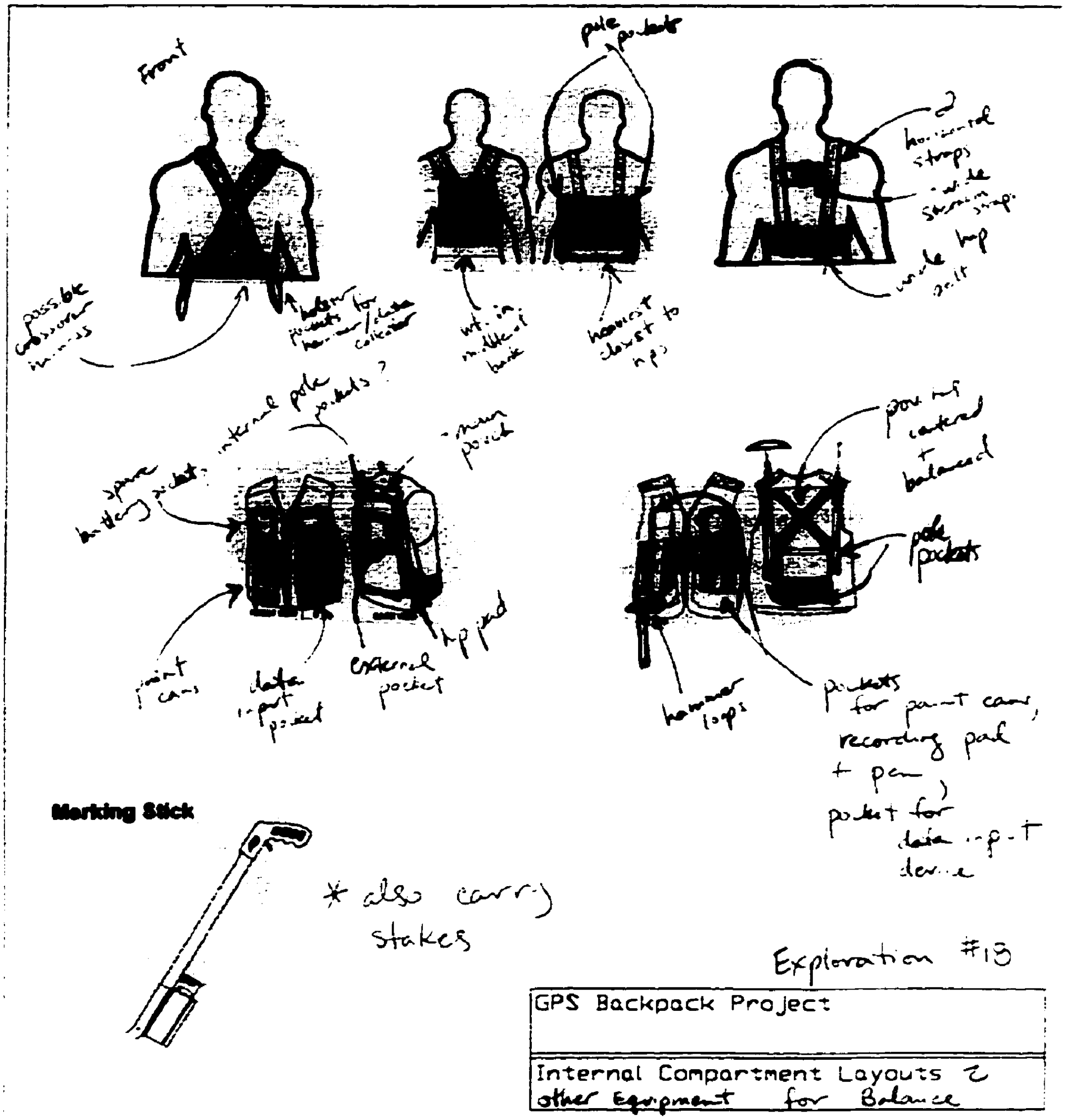


Figure #32 – Ideation

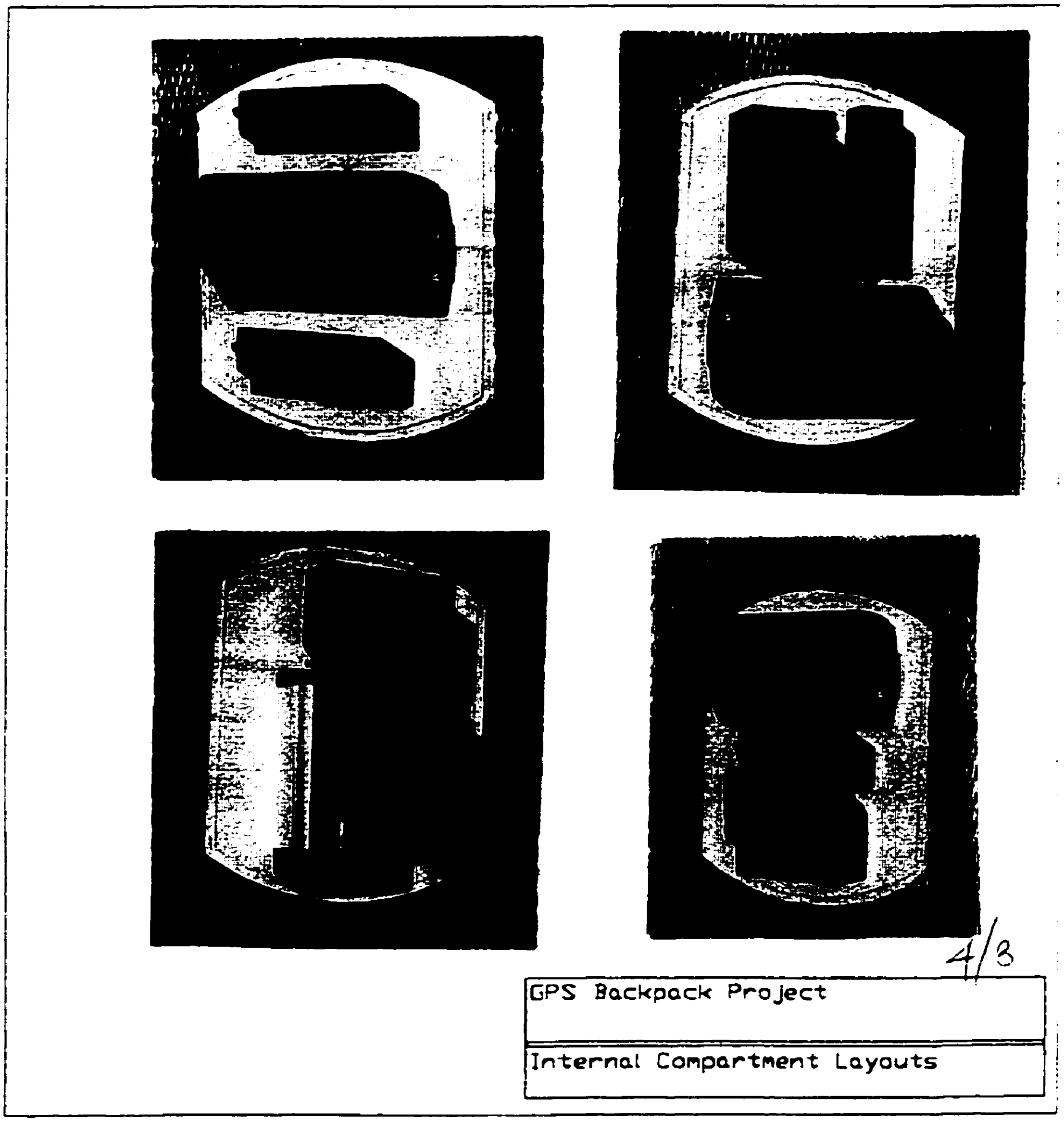


Figure #33 – Layout Planning

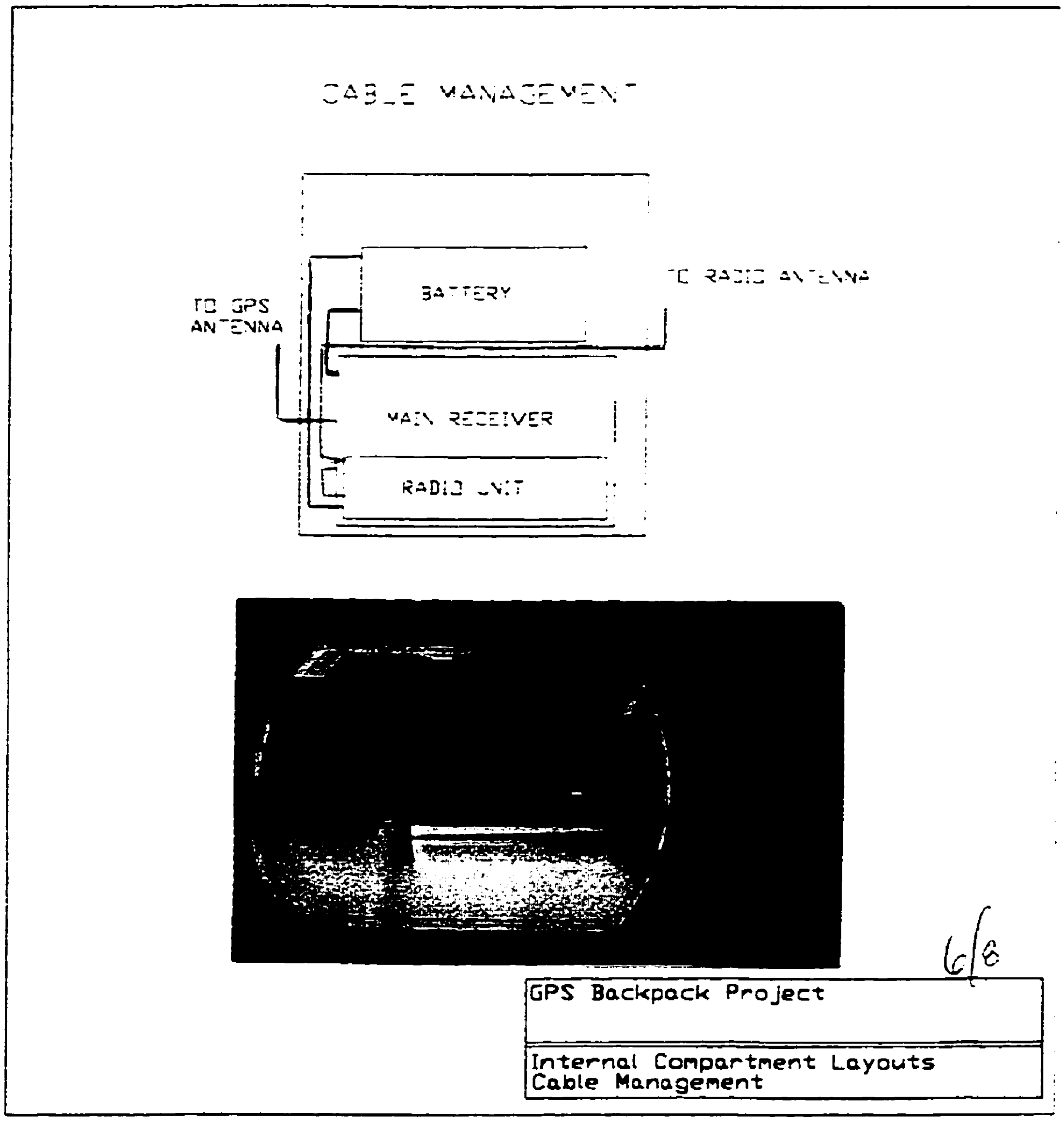


Figure #34 – Layout Planning

5.1. BACKPACK CONCEPTS

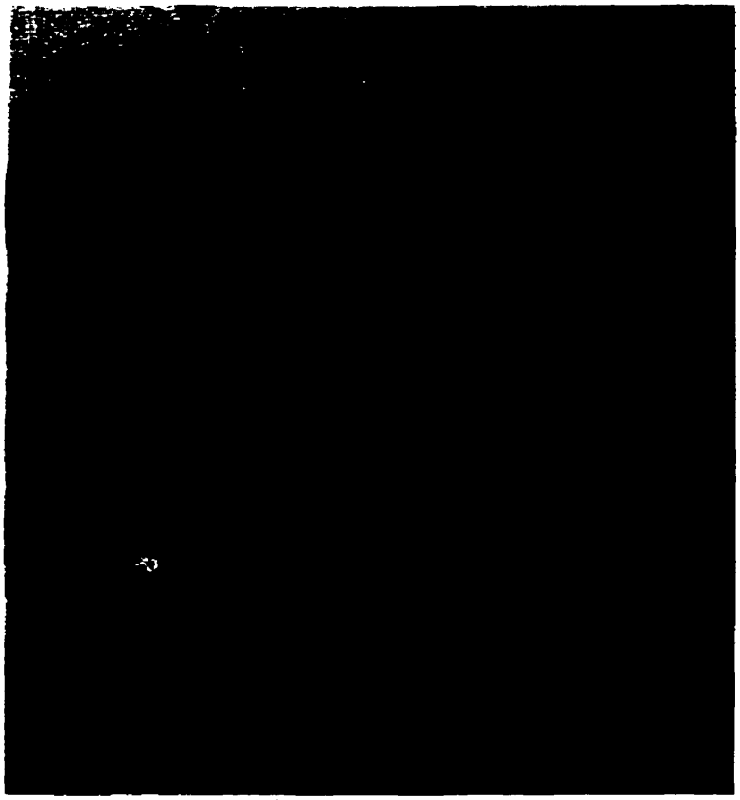


Figure #35 – Backpack Concept 1

BACKPACK CONCEPT 1 - front and rear pouch system, **Figure #35**

A front and rear pouch system is thought to better distribute weight to improve balance. The purpose is to reduce physiological strain and musculoskeletal stress. A lower load in the front would make this concept user-friendly for males or females. Consideration of suitability for the job is of primary concern.

A two bag system would rate low in:

- ease of loading batteries or other GPS equipment
- reducing weight of cables (weight may possibly increase due to more cable-carrying capacity)
- ease of putting on taking off the equipment pack.

Careful planning of the packing order of equipment would be required to maintain a symmetrically balanced load.

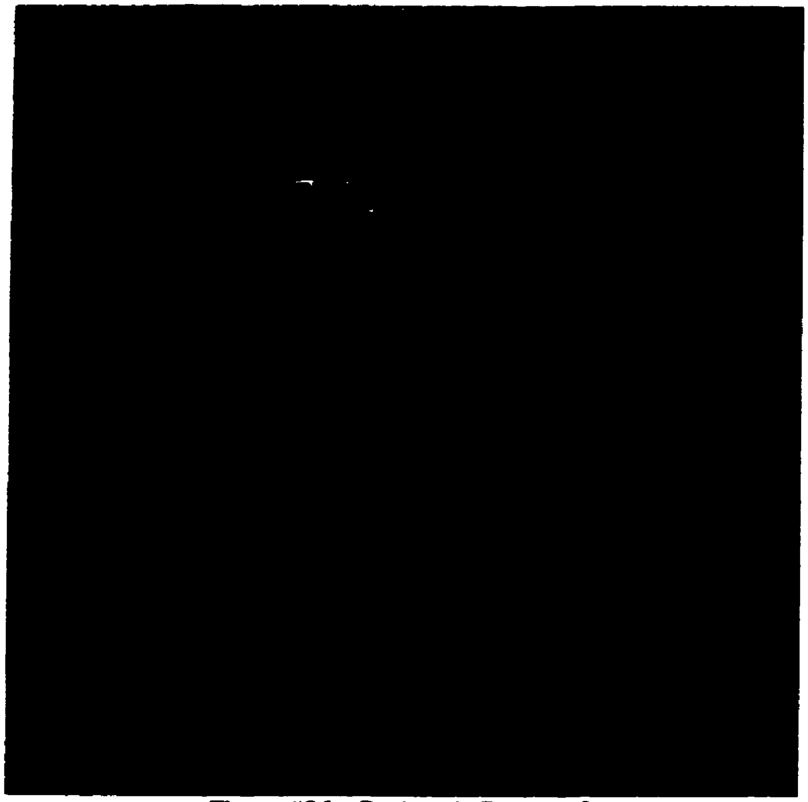


Figure #36 – Backpack Concept 2

BACKPACK CONCEPT 2 - single pouch backpack, **Figure #36**

A close fitting, body-hugging, single pouch backpack would maintain balance for the user. In addition, the hip pads are wide and corresponding useable pockets can be incorporated. The aim is for overall comfort. Overall usability would depend on an efficient means of transporting the GPS load.

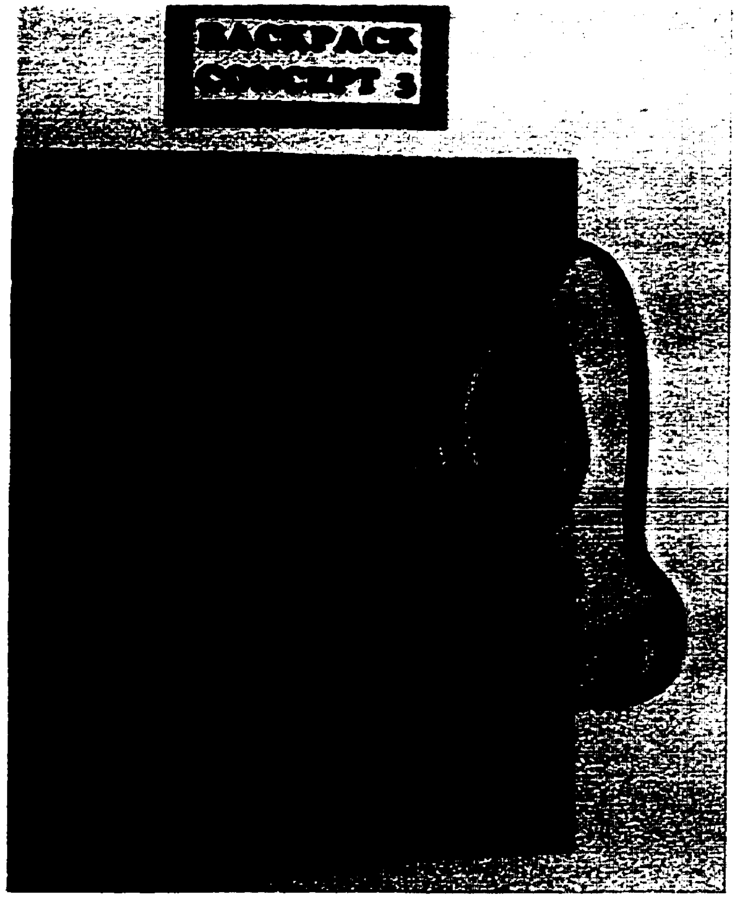


Figure #37 – Backpack Concept 3

BACKPACK CONCEPT 3 - backpack/fanny-pack hybrid, Figure #37

A unit that is half backpack and half fanny-pack with large front pockets on the shoulder straps, is one way to address weight distribution of the load. However the concept of multiple pouches as opposed to one large pouch could prove restrictive in loading and accommodating equipment.

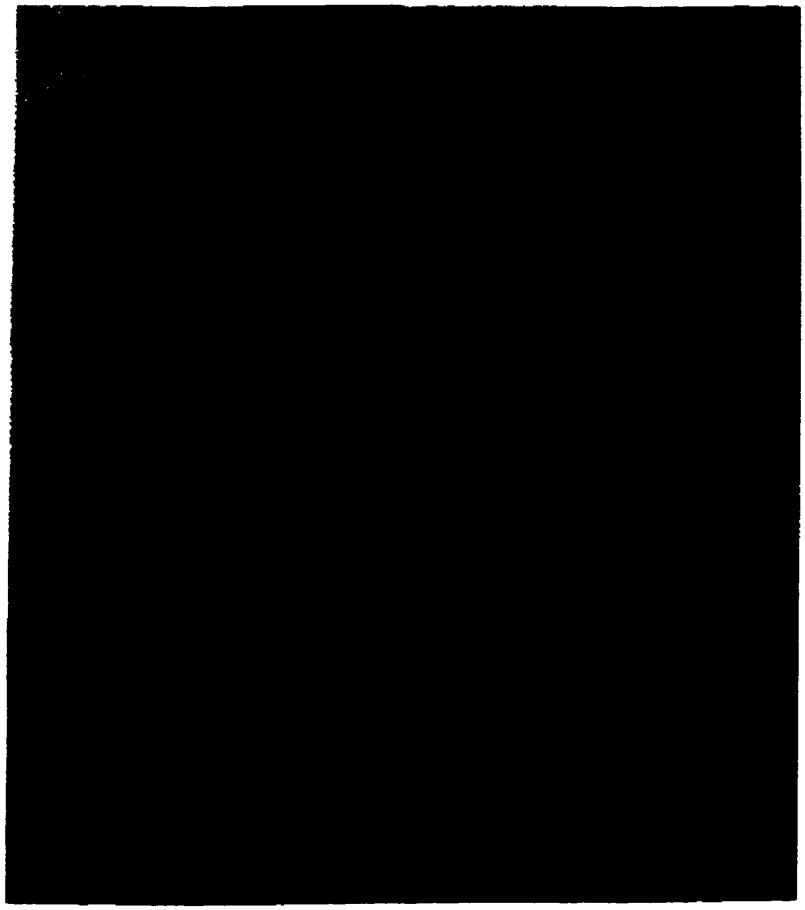


Figure #38 – Backpack Concept 4

BACKPACK CONCEPT 4 - hard shell unit, **Figure #38**

A hard shell unit with a backpack harness system would protect the equipment. In addition, the GPS external antenna could be mounted directly onto the shell. The harness system would need to be well padded to protect the body from the rigid unit. An evaluation of this concept may show higher levels of physiological stress (heart rate and rate of perceived exertion) due to the weight and size of the unit. Musculoskeletal stress would have to be addressed due to possible body part discomfort that may occur with such a unit.

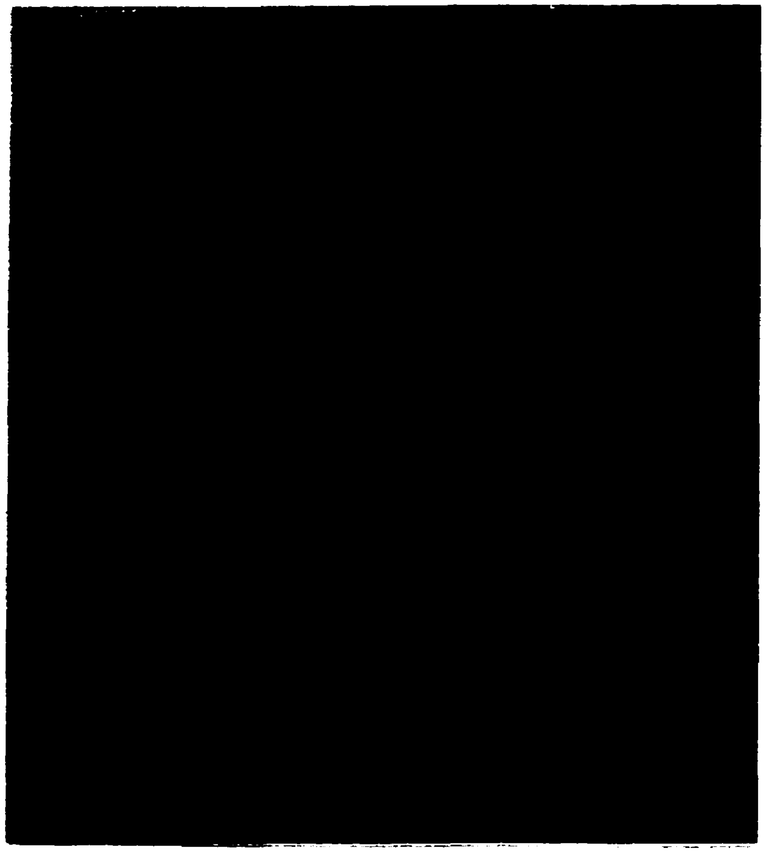


Figure #39 – Backpack Concept 5

BACKPACK CONCEPT 5 - vest-pack. **Figure #39**

A vest-like backpack could present an acceptable visual image with surveyors, as vests are common attire. The load would have to be a symmetrically-balanced load during use as improper loading could cause the system to slip around on the user and cause discomfort especially in the throat area. While this particular system would be easy to put on, overall usability attributes would necessitate further exploration.

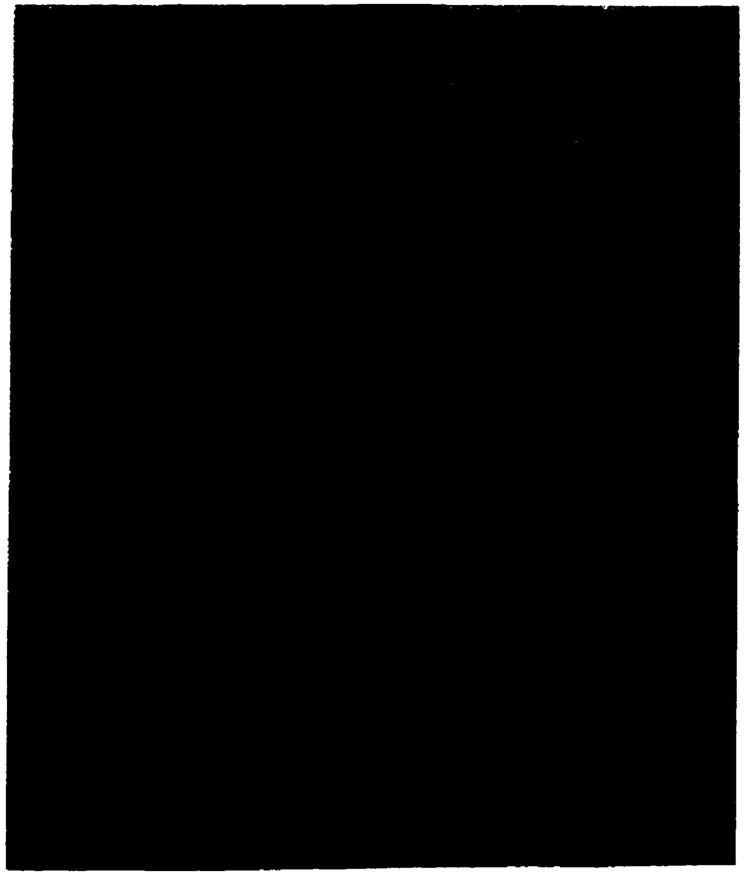


Figure #40 – Backpack Concept 6

BACKPACK CONCEPT 6 - tear-drop with front pouch, **Figure #40**

A tear-drop, double pouch system with a front pouch that enables the user to enter would make work activities more efficient. The weight distribution is in the front and back and on the hips. The goal is to make shoulder straps more comfortable. The low riding weight on the hips is an attempt to create musculoskeletal comfort. The main drawback is that it is relatively awkward to put on and remove.

Figure #41 – Backpack Concept 7

BACKPACK CONCEPT 7 - pack-board, **Figure #41**

A pack-board design that is simply a frame pack to which the equipment can be mounted would functionally improve the loading, unloading, and retrieval of visual information. The goal is to create a significantly easier pack to use. It would necessitate a pack harness that is both comfortable and functional. The ease of adding or deleting equipment as needed, contributes to speed of use with this design, assuming this is a functional requirement. This system has good potential, but protection for the equipment from weather and possible mechanical damage, needs to be pursued.

5.2 PRODUCT IDEAS

Based on the exploration of the current GPS market and with the surveys, interviews, and focus group with experts in the field, two product ideas and one idea that should be explored further were identified.

The two product ideas were used for field testing. From the field testing, an idea for another system was presented. This idea became the Final Backpack Design.

Objectives for the GPS backpack system project:

1. To construct a backpack system for Line Creek Mines that enhances the work activities of the surveyors and reduce back discomfort.

2. To further investigate a design for the system while enhancing its research and development base.

5.3 PROTOTYPE MODELS FOR FIELD TESTING

5.3.1 PROTOTYPE MODEL A

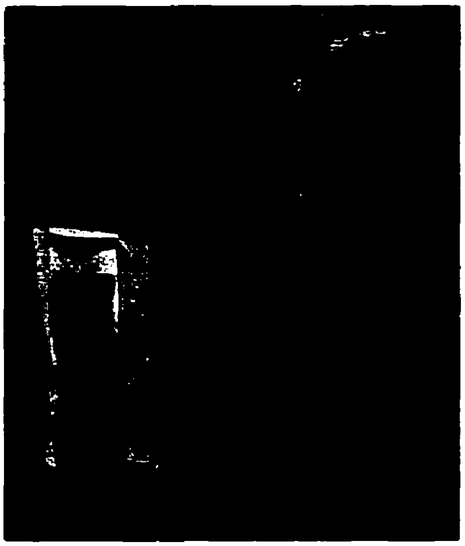


Figure #42 – Backpack Shape

Following an earlier review of the proprietary portable GPS system, two key problem areas were identified: #1 - an obvious problem pertained to weight distribution of the load due to the style of backpacks used, and, #2 - another problem pertained to cable management.

The equipment was placed into two pouches. The smaller pouch was 75% of the size of the large pouch. The users were forced to keep the flaps of the pouches open in order to connect cables and to visually inspect the LED's of the receivers.

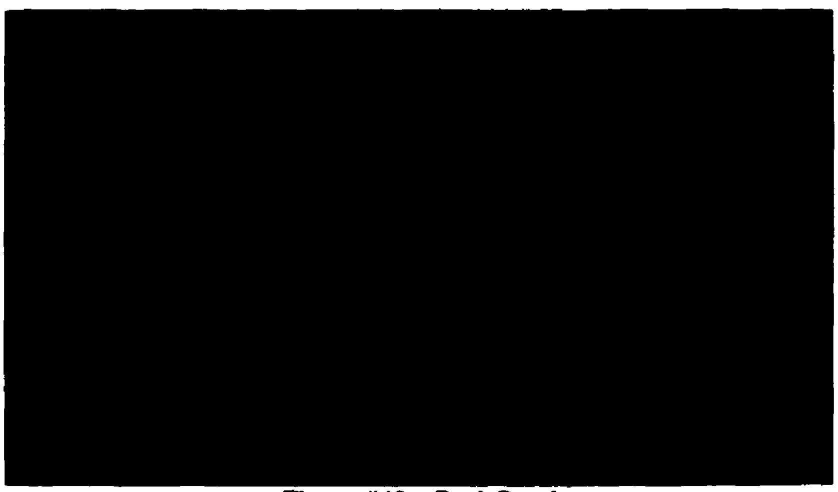


Figure #43 – Back Panels

The inability to close the flaps left the equipment exposed to dirt, moisture, rain, snow, and heat. The cables were also vulnerable to being snagged on tree branches and shrubs. The equipment inside the pouches shared the space with excess cable which contributed to a heavier load than necessary. The equipment sat unsecured in the pouches and shifted from side to side causing some destabilization for the user when negotiating rough terrain.

Two solutions were created to offer immediate improvements to the current backpack system. The principles for the two prototypes adhere to efficient load-carriage and to overcoming usability problems. Information gained from the task analysis, surveys, interviews, and the focus group were applied.

Model A is designed to be compact and to sit close to the body. The majority of the weight is carried midway on the back between the shoulders and waist, as shown in **Figure #42**. This solution addresses weight distribution. The shape of Model A makes it easy to maneuver in confined spaces. Visually, the pack appears vest-like. Wide shoulder straps and
hip pads are fully padded for comfort and assist in distributing the weight of the load over a larger area.

In addition, the back panel is also double padded to protect the body from the hard edges of the equipment. Channels are sewn horizontally on the back panel for air circulation to relieve heat and perspiration. The hip pads are double with a sewn in padded shelf to sit comfortably on the hips, and is shown in **Figure #43**.

Figure #44 – Pole Pockets

Figure #45 – Cable Slots

Separate pole pockets are attached close to the body and on the sides to provide stability and to act as a frame, as in **Figure#44**. Slots are inserted on the sides of the pack , as in **Figure #45**, to allow cables to run to the antennas and the pole pockets protect these slots from rain and snow. A clear view panel is incorporated on one side of the pack for visibility so the user can easily check the LED's of the equipment.

Internal pouches are made of netting for breathability of the equipment to help maintain a consistent temperature and avoid overheating problems with the electrical components. The internal pouches are organized so that the equipment is stacked and distributed evenly, and demonstrated in **Figure #46**. The equipment is also logically organized to reduce weight from unnecessary lengths of cable. An additional pocket on the flap stores the antenna heads that screws off when not in use. When the antenna heads are in use, the pocket can be utilized for personal items or additional equipment.

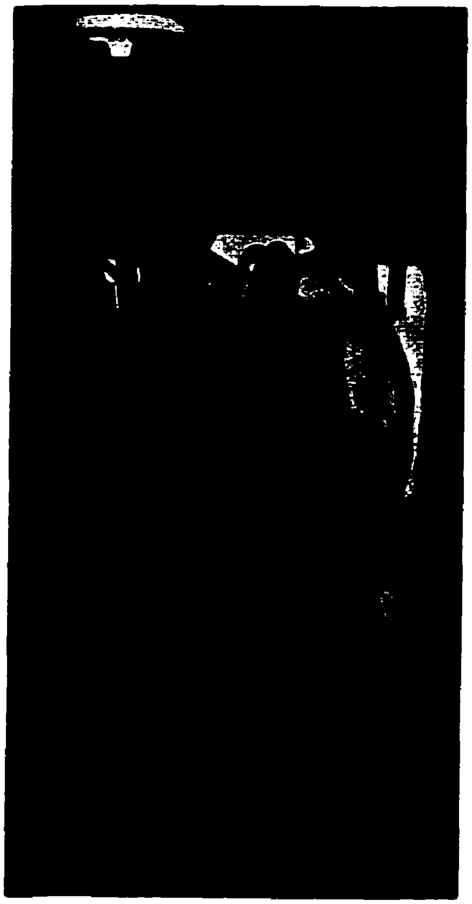


Figure #46 – Stackable Pouches

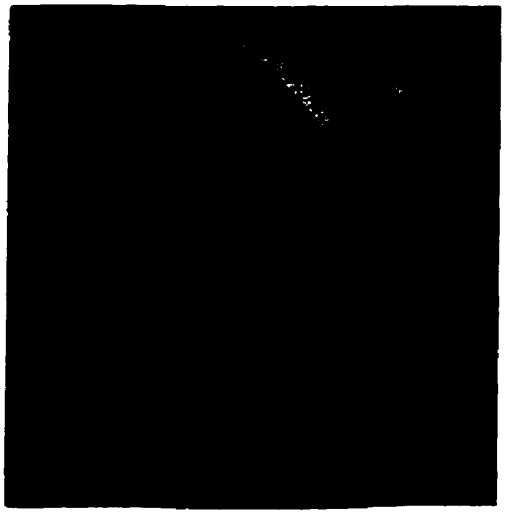


Figure #47 – External Loop Pocket

The construction of the pack is such that it is one singular pouch which unzips for easy access. The single compartment is less restrictive during loading and loading of toggles makes it easy for gloved hands to open and close the compartment. A pocket on the outside of the flap carries written and recorded material, as well as maps.

For functionality, hammer loops and loops for spray paint cans are placed on the hip pads. By referring to **Figure #44**, you will see the loops. A pocket is placed on one of the shoulder straps for holding the data input device while writing, paint marking, and hammering in stakes. The users previously either held the data input device between their knees or placed it on the ground. This external loop pocket, shown in **Figure #47**, is designed so as not to collect water or snow while working in those types of weather conditions. A large chest strap holds the S-shaped shoulder straps together using Velcro. The purpose is for comfort and added stability and is quick to remove or attach.

5.3.2 PROTOTYPE MODEL B

The pack is made of 1000 denier Cordura for its durability and water resistant properties. All stitching is 50/50 cotton/polyester, as the cotton expands and seals the seams if they become wet. The color is bright orange for maximum visibility while working outdoors and in the mine pits. In addition, "safe-bright" reflective tape is applied for visibility in changing light conditions. The color intensity of the Cordura will eventually become dull from coal dust, however, the reflective tape will retain its visibility properties.

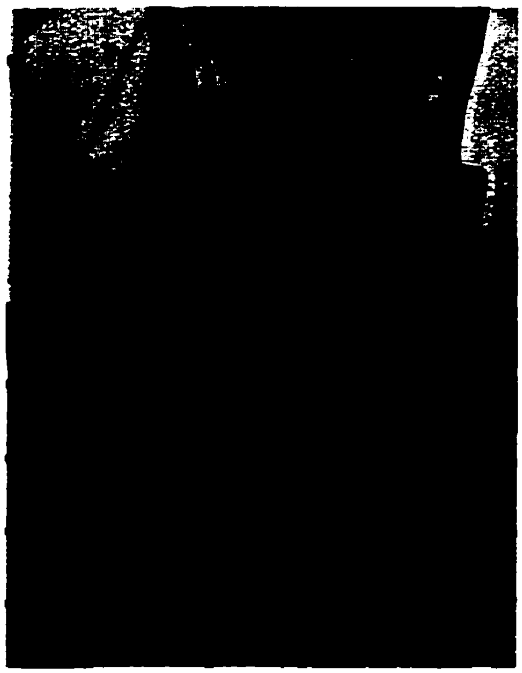


Figure #48 – Hip and Shoulder Adjustability

Appendix #14 and #15 show the Pattern Design.

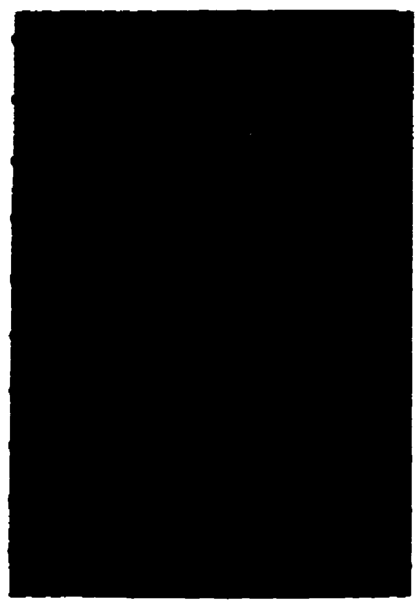


Figure #49 – Data Collection Device Holster

Model B is essentially the same pack, with the exception of some task functionality features. These features include hip and shoulder strap adjustability, as in **Figure #48**, a data input device holster, and the inclusion of a pen/pencil pocket. The purpose of these changes are to identify which model is most used and why.

The shoulder straps are adjusted by tightening or loosening the straps using a slider. The hip belt is either tightened or loosened by using a Velcro/webbing system at the waist. The holster is made of net material, shown in **Figure #49**, to avoid moisture collection and is located on the opposite hip of the hammer and spray paint can loops. It may be determined to which side it is best located at a later date. The object of the change is to determine if this a better location for a data input device pocket rather than at the chest where it may impede bending activities. A pen/pencil pocket was attached to the shoulder strap near the chest strap. The padding protects the user from the pen/pencil protruding into the body.

5.4 FINAL BACKPACK DESIGN

Figure #50– Back View of Final Design

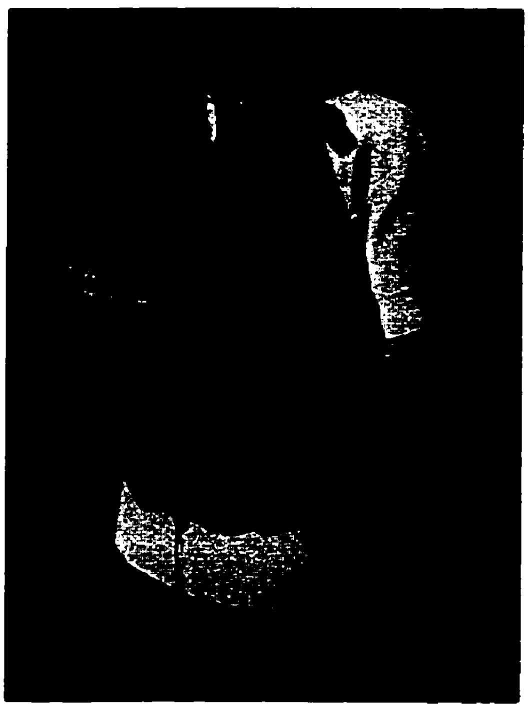
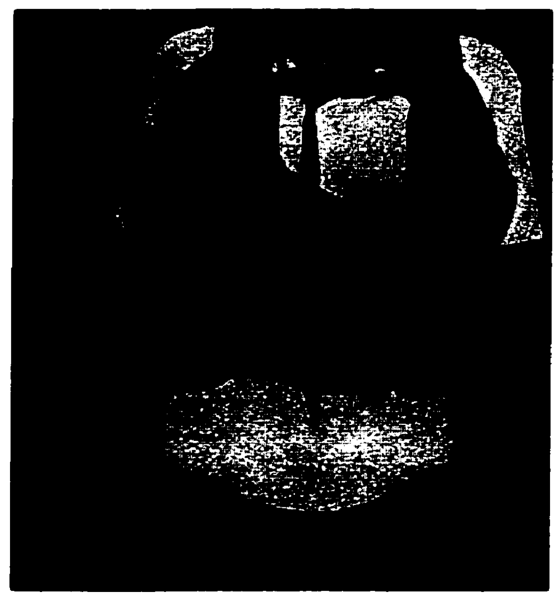


Figure #51– Vest-like Appearance



The final backpack design remains compact and closely sits on the body, as shown in **Figure #50**. The internal pocket design did not change. Visually, the pack even appears more vest-like than the Prototype Models, as demonstrated in

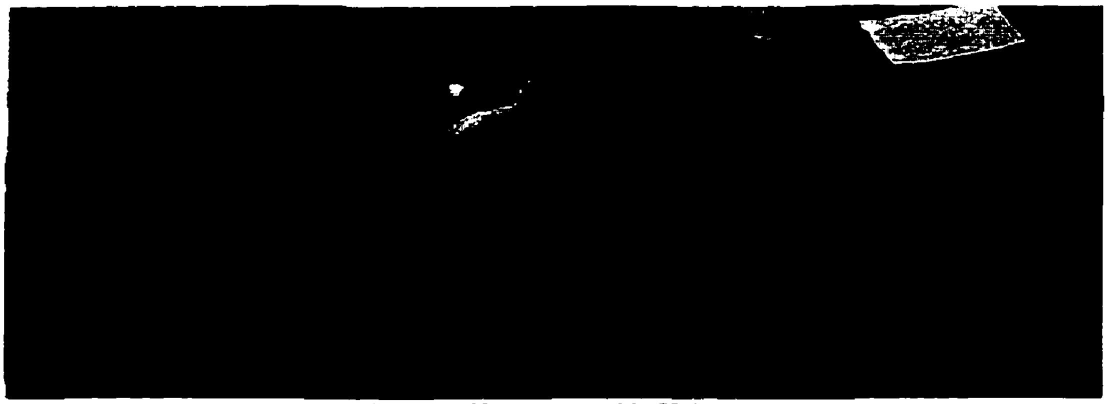


Figure #52 – Removable Holster

Figure #51. The back panel is slightly wider at the bottom to sit on the hips in order to attach a traditional hip belt. The back panel also contains a rigid plastic insert for stiffness and to protect the back from the equipment.

An interchangeable holster and hammer holder allows for any handedness preference. This holster can also be removed if the user prefers, and can be seen in **Figure #52.**

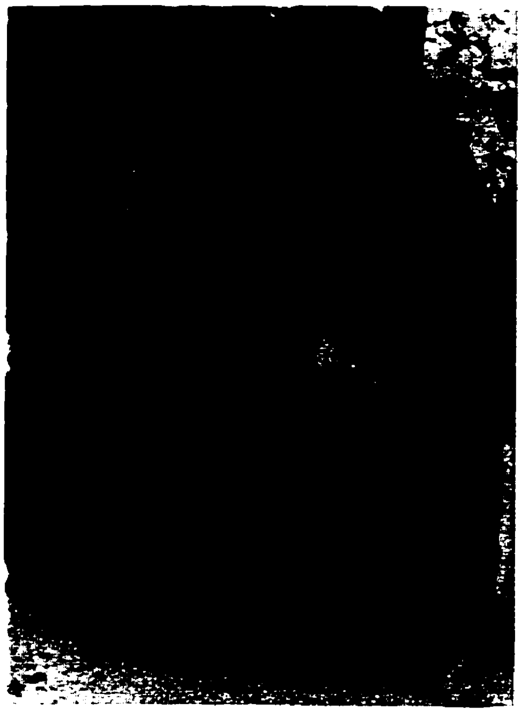


Figure #53 – Waterbottle/Spray Paint Pocket on Breathable Vest Front Piece

The front pockets remain separate for pens and pencils, as well as a pocket that can hold either a paint can or a water bottle. The pockets are a part of the front panels where there is an additional zipper pocket for items as needed. **Figure #53** and **Figure #54** show the removable vest pieces where the pockets are mounted, and the breathable mesh material used. This backpack can be used for wireless GPS devices or with the current system.

The most important feature of this backpack is the fact that certain components (internal pockets, data collector holder, front panels and hammer holder) can be removed and replaced with a configuration appropriate for subsequent equipment.

Figure #55 shows the changeable equipment pockets, and **Figure #56** shows the internal layout of the pocket system. Mesh is still used for breathability, but the pockets are solid material so that the equipment slides easily into the pockets. The rationale for the pockets to be removable is so that they can be replaced if new GPS equipment is purchased. The backpack system can remain current with the advancement of technology. When the equipment needs repair, you can still use the backpack, simply by changing the pockets to fit the equipment.

Figure #54 – Pen Pocket on Vest
Front Piece

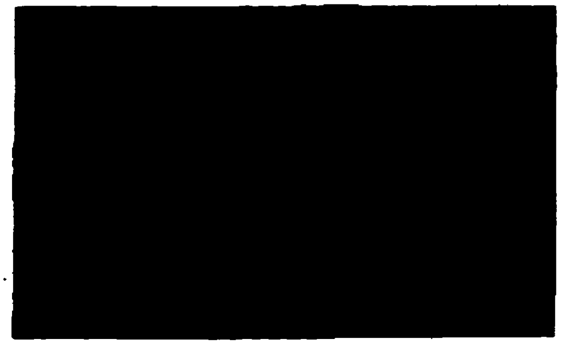
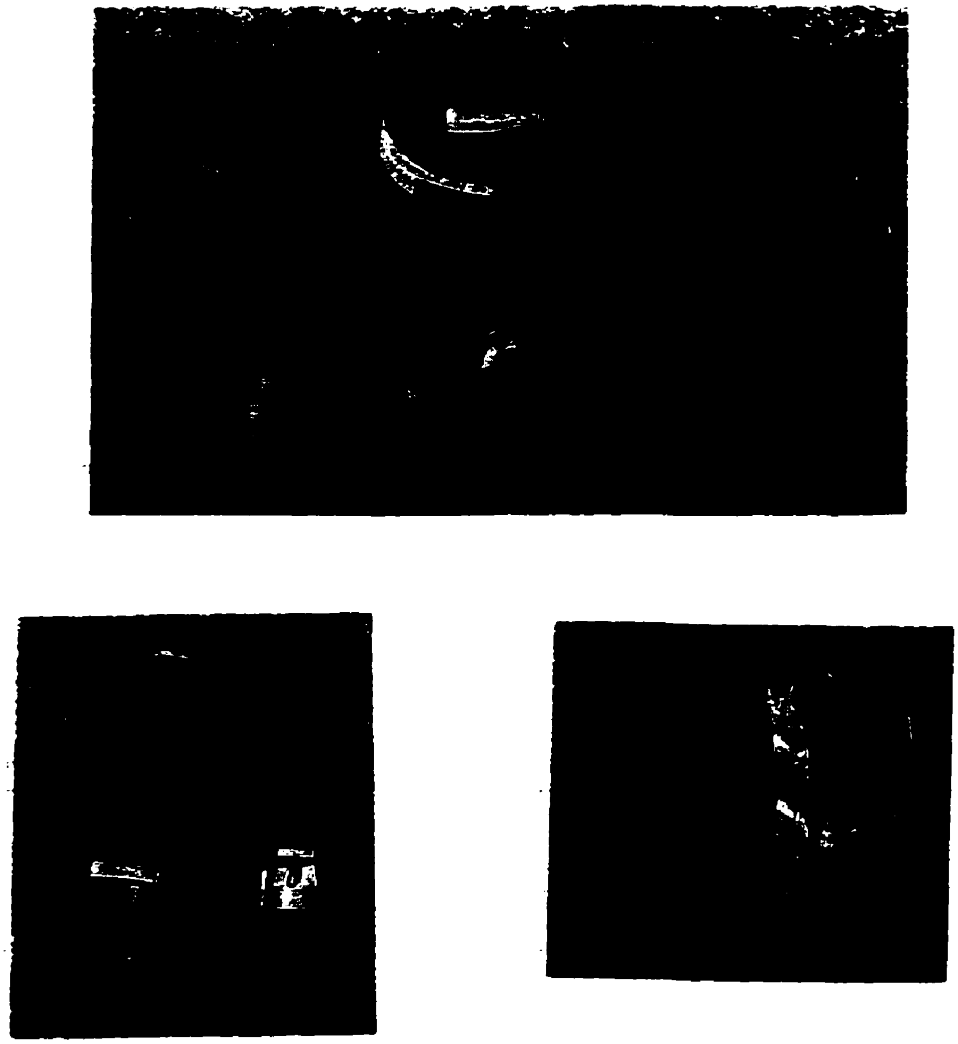


Figure #55 – Equipment Pockets

Views of the Backpack System is shown in **Figure #57**. The entire system comes in six separate pieces, and can be entirely customized to fit any need. The Final Backpack Design addresses cable management and end user considerations.

Figure #56 – Internal View of Layout



BACKPACK PROJECT

FINAL DESIGN PHOTOS

Figure #57 – Backpack System

6. PROJECT SUMMARY

PROBLEM - Portable GPS equipment has been on the market for ten years. Linecreek Mines incorporates the use of two such units for a variety of pit mine specific surveying activities. The current backpack system used for the portable GPS equipment reflects a lack of end user considerations. A change in the current system would decrease discomfort while using the GPS equipment.

PROCESS - The problem was explored by a multi-phased approach that consisted of:

- a literature review
- task and design analysis
- a survey and focus group
- inventory of current backpacks
- consultation and interviews of users as to the function of carrying portable GPS equipment
- exploration of types of carrying devices for their usability
- investigation of structural components of carrying devices
- problem identification
- design development

RECOMMENDATIONS

The following needs were identified:

- the carrying device should address cable management, without exposing other equipment
- a focus on the end user should provide intuitive use of the carrying device
- a lighter weight complete system would reduce the back discomfort, while allowing space for the user to carry necessities
- the carrying device should also provide the safety feature of being visible for pit mine survey activities
- to better serve the users in their GPS survey activities the final design should include the added features of a data collector pocket, hammer loops, a convenient view of LED's, and have a vest-like fit.

CONCLUSION - A design was developed and created based on the above criteria. The Prototype models, and design specifications have been provided to Linecreek Mines. It should be noted that any design improvements on their own would not fully address the problems associated with carrying portable GPS equipment. It is only through a holistic approach to end user ergonomics and design, including GPS equipment design, that the overall problems can be fully resolved.

This project clearly addresses functionality. The recommendations stated provide an awareness for future design development. However, the next step would be to investigate and identify materials that this product could be constructed of.

APPENDIX #1

QUESTIONNAIRE AND
INTERVIEWS FOR
GPS/BACKPACK USERS

Faculty of Environmental Design, University of Calgary

The purpose of the questionnaires and interviews is to collect information about using the backpack system for GPS survey work. This is part of a joint project between the Faculty of Environmental Design, The University of Calgary, for a Masters Degree Project, and LineCreek Mines, Luscar Ltd., Sparwood, B.C. Your completion of the questionnaire and participation in the interview is voluntary, however, your accurate responses will provide important information into the proposed design of a more efficient GPS backpack.

All responses are **confidential**, your identity will be protected, and only composite information gathered from the questionnaires and interviews will be provided to LineCreek.

Your decision to complete and return questionnaires will be interpreted as an indication of your consent to participate.

Only those who indicate a willingness to participate in the interview prior to the date of my visit will be contacted. Your name will not be released whether or not you decide to participate in the interview.

THANK YOU FOR YOUR TIME AND EFFORT IN COMPLETING QUESTIONNAIRES AND PARTICIPATING IN THE INTERVIEW. THIS INFORMATION IS VERY IMPORTANT FOR THE PROJECT.

IF YOU HAVE ANY QUESTIONS OR CONCERNS ABOUT INVOLVEMENT IN THE PROJECT PLEASE CONTACT VIVIAN LUOMA AT 277-0298, OR AT viluoma@3web.net.

Appendix I: Questionnaire and Interviews for GPS Backpack Users

APPENDIX #2

FACULTY OF ENVIRONMENTAL DESIGN

UNIVERSITY OF CALGARY

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Please take the time to read this form carefully and to understand any accompanying information.

The purpose of this project is to design a backpack to carry GPS/GIS equipment for Linecreek Mines. Your participation in the **Task analysis** will involve being observed in your typical work practice while using the GPS/GIS equipment, answering questions relating to your experience using the GPS/GIS equipment, and being videotaped or having still photographs taken of you while working. A copy of this consent form will be given to you for your records and reference

Disruption and inconvenience to your work will be kept to a minimum. Linecreek mines supports your participation in this project if you wish to volunteer.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time. Your continued pariticipation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you have further questions concerning matters related to this research, please contact Vivian Luoma, 403-282-0621. If you have any questions concerning your participation in this project, you may also contact the Faculty of Environmental Design; please ask who to speak to.

I agree to participate in this project by participating in a Task Analysis. I agree to video and/or still photographs of me for the purpose of designing a backpack.
Participant ______________________________
Date ______________

I consent to the use of video and/or still photographs of me being used in presentations of this project.
Participant ______________________________
Date ______________

Appendix II: Consent Form

APPENDIX #3

CHECKLIST FOR TASK ANALYSIS OF USING A GPS/GIS BACKPACK UNIT

WORK AND EQUIPMENT CHARACTERISTICS

_____ extended lateral or forward reaches, unnecessary twisting, at or beyond normal
_____ inaccessible/inadequate backpack room for equipment, materials, and personal items
_____ backpack is difficult to adjust before wearing
_____ backpack has inadequate back support or in incorrectly placed
_____ lack of or inadequate padding
_____ doesn't use adjustable straps
_____ backpack design leads to inefficient motions
    _____ for recording data
    _____ for positioning for data readings
    _____ reaching
    _____ other:

_____ awkward postures are required for carrying backpack
_____ lack of built-in adjustability in backpack
_____ backpack sits too high or too low
_____ workers frequently adjust backpack
_____ workers adapt backpack: add padding _____
    add other supports _____
    other:

_____ buckles/zippers/etc. are difficult to use
_____ body is held in a static position to maneuver with wearing the GPS/GIS backpack unit
_____ insufficient stabilizing of equipment
_____ inadequate stability in backpack/ equipment not distributed properly
_____ inadequate hip padding
_____ inadequate shoulder padding
_____ padding not located in proper places, indicate:

_____ pinch points of soft tissue are not adequately guarded
_____ equipment controls are at uncomfortable locations
_____ task requires handling of difficult to grasp objects
_____ static muscle loading
_____ edges of equipment exerts pressure, specified points:

_____ workers complain of fatigue and discomfort:
    _____ neck
    _____ shoulders
    _____ upper back
    _____ lower back
    _____ other:

_____ motor range requirements are anatomically unacceptable
_____ high precision motion requirements for extended time
_____ requires frequent motion patterns
_____ requires continual adjustment of equipment components for comfort to maintain data collection
_____ cable management of equipment is a problem
_____ other observation:

Appendix III: Checklist for Task Analysis

APPENDIX # 4

QUESTIONNAIRE FOR GPS/GIS BACKPACK UNIT USERS

The purpose of this questionnaire is to collect information about GPS/GIS backpack unit use. The completion of the questionnaire is voluntary, however, your accurate responses will provide important information into the proposed design of an efficient backpack. All responses are CONFIDENTIAL, your identity will be protected, and only composite information gathered from the information will be used. Your decision to complete this questionnaire will be interpreted as an indication of your consent to participate.

1. Gender - Male ____ Female ____
2. Age - <30 yrs. ____ 30-40 ____ 40-50 ____ >50 yrs. ____
3. Position - surveyor ____ engineer ____ other ____ indicate: ____________________
4. Work area - indicate: ____________________
5. How long have you worked in this type of position?
   <1 yr. ____ 1-5 yrs. ____5-10yrs. ____11-15yrs. ____>15 yrs. ____
6. How many hours in one shift do you typically carry the GPS/GIS backpack equipment?
   <2hrs. ____ 2-4 hrs.____ 5-7 hrs. ____ >7hrs. ____
7. How many hours in one week do you typically carry the GPS/GIS backpack equipment?
   <10 hrs. ____ 10-20 hrs. ____ 21-35 hrs. ____ >35 hrs.____
8. Are you assigned your own GPS/GIS backpack unit? Yes ____ No ____
   If no, how often do you share or change the GPS/GIS backpack unit?
   Daily ____ Weekly ____
9. Do you adjust the GPS/GIS backpack to suit your needs? Yes ____ No ____
   What do you adjust? indicate: ____________________
10. In the past three months, have you experienced any back discomfort or pain (e.g.. aching, jabbing pain, back muscle tenderness) while you working? Yes ____ No ____
    If yes, did it occur while you were carrying the GPS/GIS backpack unit?
    Yes ____ No ____
    If you answered no, please proceed to question 16.
11. If you experienced pain or discomfort, please indicate the area:
    neck ____ upper back ____ lower back ____ shoulder blades ____
    hips ____ shoulders ____
12. Were the symptoms on the: right side ____ left side ____ both sides ____
13. Did these symptoms continue for more than one hour after you had stopped carrying the GPS/GIS backpack? Yes ____ No ____
14. Have you modified how you do your work as a result of these symptoms? Yes ____ No____
15. Have you received any medical treatment or rehabilitation for these symptoms?
    Yes ____ No ____
16. How would you describe your fitness level?
    Poor ____ Average ____ Above average ____ High ____
17. If you have any suggestions on how to improve the backpack, or any ideas on how you would like to see the GPS/GIS equipment carried, please comment:

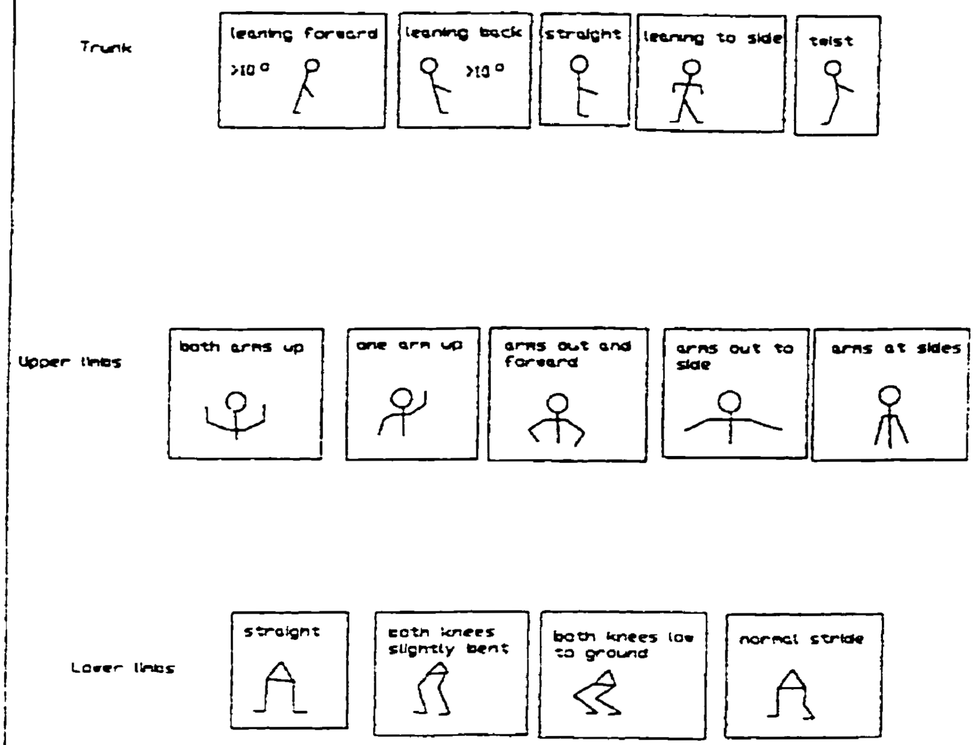
Appendix IV: Questionnaire for GPS Users

APPENDIX #5

PICTOGRAMS

SUBJECT #

10 minute intervals
job observation - 1hr 15 min



major adjustments made

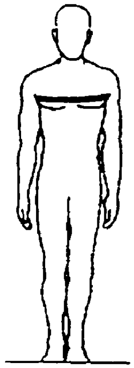
Appendix V: Pictogram

APPENDIX #6

THE BODY
Chest Circumference

CHEST CIRCUMFERENCE

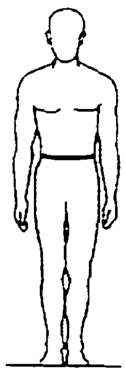
This dimension can be used in conjunction with shoulder circumference for garment design and the definition of the body characteristics of test subjects.



	Percentile		
	5th	50th	95th
Adults			
Males	34.3 in	39.0 in	44.9 in
Females	30.4 in	34.3 in	40.5 in
Boys.			
Age 17	32.5 in	36.2 in	40.8 in
Age 14	27.5 in	31.3 in	36.1 in
Age 12	25.5 in	28.1 in	32.1 in
Age 6	20.7 in	22.6 in	25.3 in
Age 2	18.0 in	19.0 in	20.6 in
Girls.			
Age 17	29.7 in	32.3 in	36.3 in
Age 14	27.6 in	30.8 in	34.6 in
Age 12	25.2 in	28.7 in	33.4 in
Age 6	20.3 in	22.3 in	24.3 in
Age 2	17.3 in	18.4 in	20.5 in
Adults age 70 and over			
Males	33.0 in	38.1 in	44.1 in
Females	30.1 in	35.0 in	39.9 in
Truck and bus drivers.			
Males	—	—	—
Females	—	—	—
Airline pilots (Male)	36.3 in	38.8 in	41.3 in
Flight attendants (Female)	31.2 in	33.7 in	36.4 in
Law enforcement officers			
Males	35.4 in	40.1 in	45.6 in
Females	—	—	—
U.S. Army			
Males	34.9	38.9	43.8
Females	32.1	35.5	40.3

WAIST CIRCUMFERENCE

This dimension can be used in conjunction with shoulder and chest circumference for garment design and the definition of the body characteristics of test subjects.



	Percentile		
	5th	50th	95th
Adults			
Males	28.4 in	34.8 in	42.9 in
Females	24.1 in	29.2 in	39.1 in
Boys.			
Age 17	26.5 in	29.6 in	35.9 in
Age 14	23.7 in	26.8 in	32.7 in
Age 12	22.1 in	24.8 in	29.7 in
Age 6	18.0 in	20.3 in	23.0 in
Age 2	15.5 in	17.3 in	19.3 in
Girls.			
Age 17	24.9 in	27.8 in	34.4 in
Age 14	23.1 in	26.8 in	31.9 in
Age 12	21.8 in	25.1 in	32.0 in
Age 6	18.1 in	20.2 in	23.1 in
Age 2	14.8 in	17.4 in	19.4 in
Adults age 70 and over			
Males	28.3 in	35.8 in	41.3 in
Females	25.9 in	33.2 in	39.9 in
Truck and bus drivers			
Males	—	—	—
Females	—	—	—
Airline pilots (Male)	29.0 in	32.0 in	35.0 in
Flight attendants (Female)	22.8 in	24.5 in	26.4 in
Law enforcement officers			
Males	30.1 in	35.3 in	42.3 in
Females	—	—	—
U.S. Army*			
Males	29.7	32.8	38.2
Females	25.1	23.2	33.2

*[illegible]

Appendix VI: Body Circumference

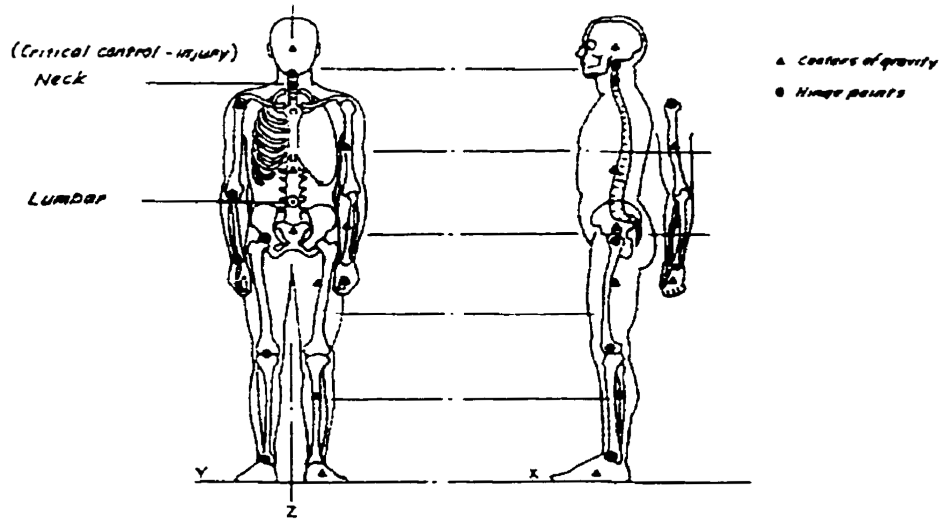
Courtesy of Workers Compensation Board of Alberta, 1998. 300-6 Ave. S.E., Calgary Alberta

APPENDIX #7

BODY MOBILITY: HINGE POINTS AND CENTERS OF GRAVITY

Mobility and posture control depend on the skeletal hinge-point locations and the weight and centers of gravity of various body components. The accompanying table and illustration present key hinge-point and c/g locations and the approximate weight of key body segments.

	Weight: lb (kg)	Percent of Total Weight
Head	10.7 (4.86)	6.9
Trunk and neck	70.7 (32.1)	46.1
Upper arms	10.1 (4.59)	6.6
Lower arms	6.4 (2.9)	4.2
Hands	2.5 (1.18)	1.7
Upper legs	33.0 (14.98)	21.5
Lower legs	14.7 (6.67)	9.6
Feet	5.2 (2.36)	3.4
Note Example total—153.4		100.0



BODY HINGE POINTS AND CENTERS OF GRAVITY

Appendix VII: Body Hinge Points and Centers of Gravity

Courtesy of Workers Compensation Board of Alberta. 1998. 300-6 Ave. S.E., Calgary Alberta

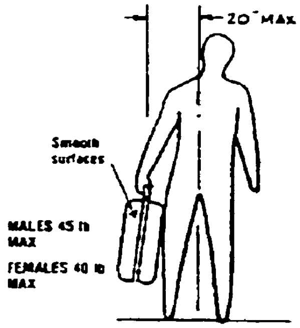
HUMAN STRENGTH Lifting and Carrying

APPENDIX #8

Weight in Relation to Carrying Mode

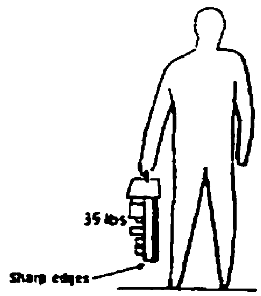
The ease with which various packages can be carried depends not only on the weight but also on the type and placement of the handles. The accompanying sketches illustrate common situations and suggested upper weight limits for typical package-carrying configurations.

1. When the package (e.g., a suitcase) has smooth sides, it can be carried against the person's hip or leg without too much stress. The weight should not exceed more than about 45 lb (20 kg) for males and 35 to 40 lb (14 to 18 kg) for females.



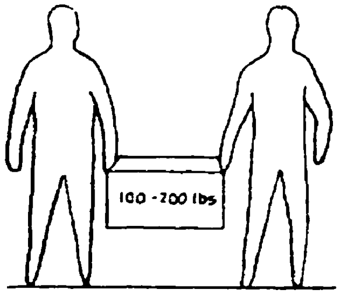
1.

2. When the package surfaces are not smooth (as is the case with electronic equipment chassis, etc.), limit weight to about 35 lb (14 kg).



2.

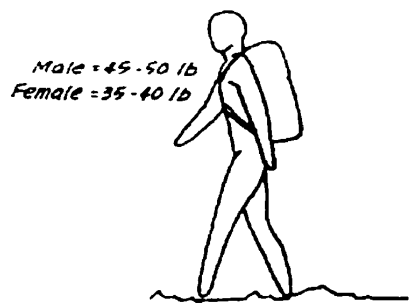
3. Although the typical male can carry an equipment package weighing up to about 60 lb (27 kg) for a short distance, this much weight should involve two persons carrying the package by means of appropriately located dual handles. Two men should not be required to carry 100 lb (45 kg) very far or more than 200 lb (90 kg) more than a short distance.



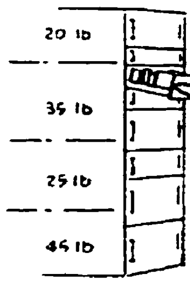
3.

4. The removal and replacement of equipment units from a rack at different heights require consideration of the suggested maximum package weights in relation to working height, as indicated in the accompanying sketch.

5. Backpack weight-carrying guidelines are indicated in the accompanying sketch.



5.



4.

Appendix VIII: Human Strength - Lifting and Carrying

Courtesy of Workers Compensation Board of Alberta, 1998. 300-6 Ave. S.E., Calgary Alberta

APPENDIX #9

DESIGN ASSESSMENT

What problem am I solving?

What design solution have I chosen?

Who is this solution for?

How has this problem been dealt with in the past?

Has something been used that wasn't originally intended for?

Does the solution really work well?

How could the design be improved?

List other concerns.

Rate the solution

Appendix IX: Design Assessment

APPENDIX #10

PRODUCT EVALUATION

Pockets are easy to access--Pockets are hard to access

Bag is useful for many tasks---------------------------------- Bag is not useful for many tasks

Bag is lightweight-- Bag is heavy

Bag is intuitive to use---Bag is not intuitive to use

Bag aids in efficient work activities----------------------Bag does not aid in efficient work

Bag is well made and durable------------------------------------Bag is not well made or durable

Bag is suited to user--Bag does not suit user

Bag is easy to fix---Bag is hard to fix

Bag works as a complete unit----------------------------Bag needs other units to be complete

Bag aids physical needs of user-----------------------Bag does not aid physical needs of user

Bag fits in the cultural context------------------------Bag does not fit in the cultural context

Bag buckles/zippers large-- Bag buckles/zippers small

Bag is highly visible for safety-- Bag is not visible nor safe

Appendix X: Product Evaluation

APPENDIX #11

	vest use	hip belt	backpack	holsters	adjustable webbing	straps with pockets	chest pack
vest use		x	x	x	x		x
hip belt	x		x	x	x	x	x
backpack	x	x		x	x		x
holsters	x	x	x		x	x	x
adjustable webbing	x	x	x	x		x	x
straps with pockets		x		x	x		x
chest pack	x	x	x	x	x		x

	adjustable	lightweight	visible	wide straps	large buckles	equipment secure	data collector pocket	pen pocket	velcro
adjustable		x	x	x	x	x	x	x	x
lightweight	x					x	x	x	x
visible				x	x		x	x	x
wide straps	x		x		x	x			x
large buckles	x		x	x		x			
equipment secure	x	x		x	x		x	x	x
data collect pocket	x	x	x			x			
pen pocket	x	x	x			x			
velcro	x	x	x	x	x	x			

	educate employees on pack use	design a more useable backpack	pack dogs/ donkeys	purchase new equipment
educate employees on pack use		x		x
design a more useable backpack	x			x
pack dogs/ donkeys				
purchase new equipment	x	x		

DECISION MAKING MATRIX FOR DESIGN OPTIONS

Appendix XI: Decision Making Matrix for Design Options

APPENDIX #12

POST FIELD TEST SURVEY

1. How long did you use Model A? ______________________

2. How long did you use Model B? ______________________

3. What were your reasons for using Model A? ______________________
____

4. What were your reasons for using Model B? ______________________
____

5. How do you rate Model A?

   poor ( )   mediocre ( )   good ( )   other: ______________

6. How do you rate Model B?

   poor ( )   mediocre ( )   good ( )   other: ______________

7. What would you say are the main advantages of Model A? ______________
____

8. What would you say are the main advantages of Model B? ______________
____

9. What would you say are the main disadvantages of Model A? ______________
____

10. What would you say are the main disadvantages of Model B? ______________
____

11. On the whole would you say the advantages of the new models outweigh the old model?

    yes _____   no _____   don't know _____

12. Other comments:

Appendix XII: Post Field Test Survey

APPENDIX #13

POST FIELD TEST INTERVIEW

SATISFACTION

How do you feel about backpack model A?

How do you feel about backpack model B?

These questions attempt to measure the general feeling of satisfaction or dissatisfaction on a scale of 1 to 5.

NET IMPROVEMENTS

On the whole, would you say that the design improvements of the new models outweigh the old backpack that was used?

This question attempts to measure the positive and negative perceptions on a scale of 1 to 5

JOB ACTIVITY CHANGE

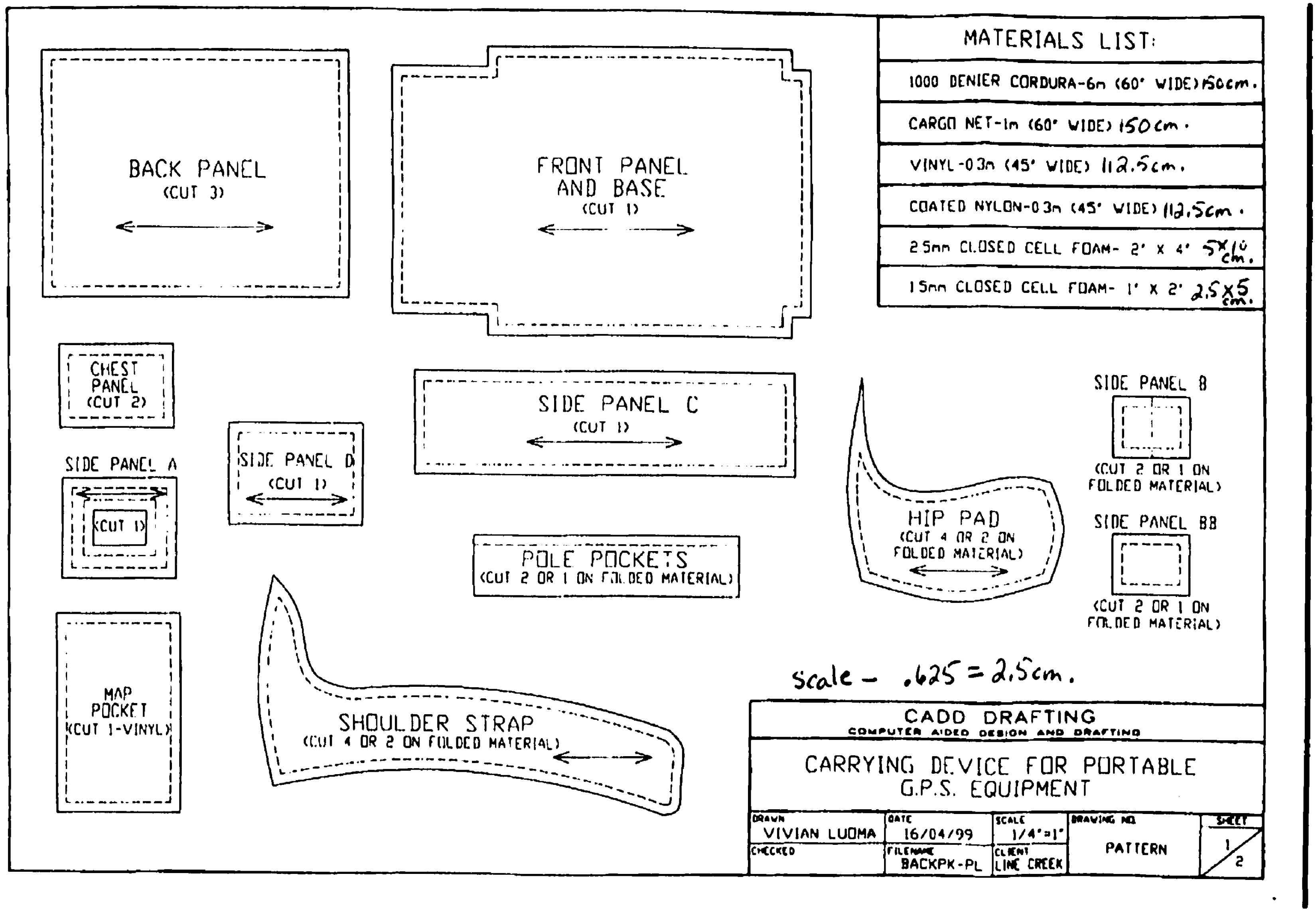
Do you think that by using the backpack Model A has changed the way you perform your job?

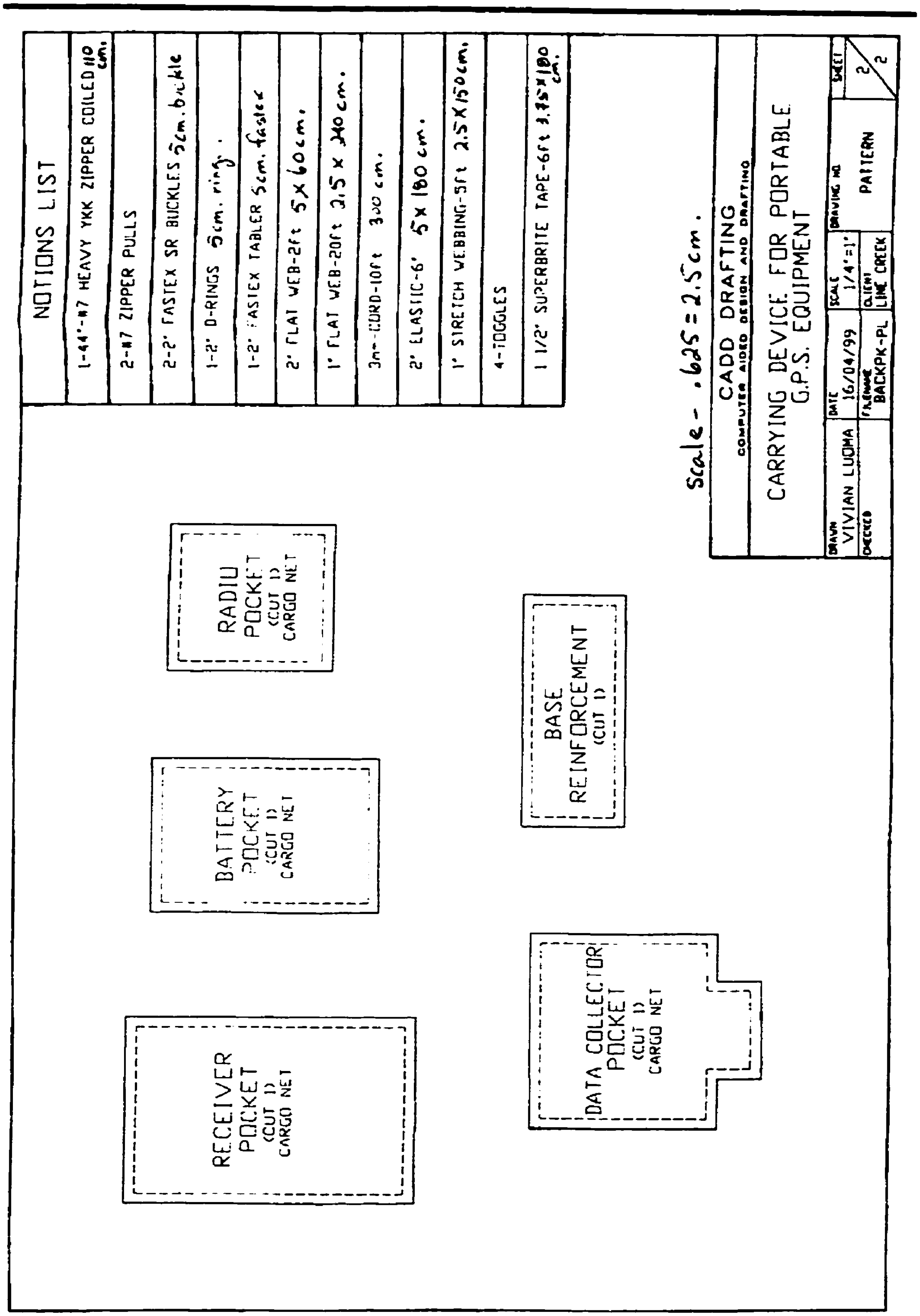
Do you think that by using the backpack Model B has changed the way you perform your job?

These questions attempt to measure the positive and negative perceptions on a scale of 1 to 5

Appendix XIII: Post Field Test Interview

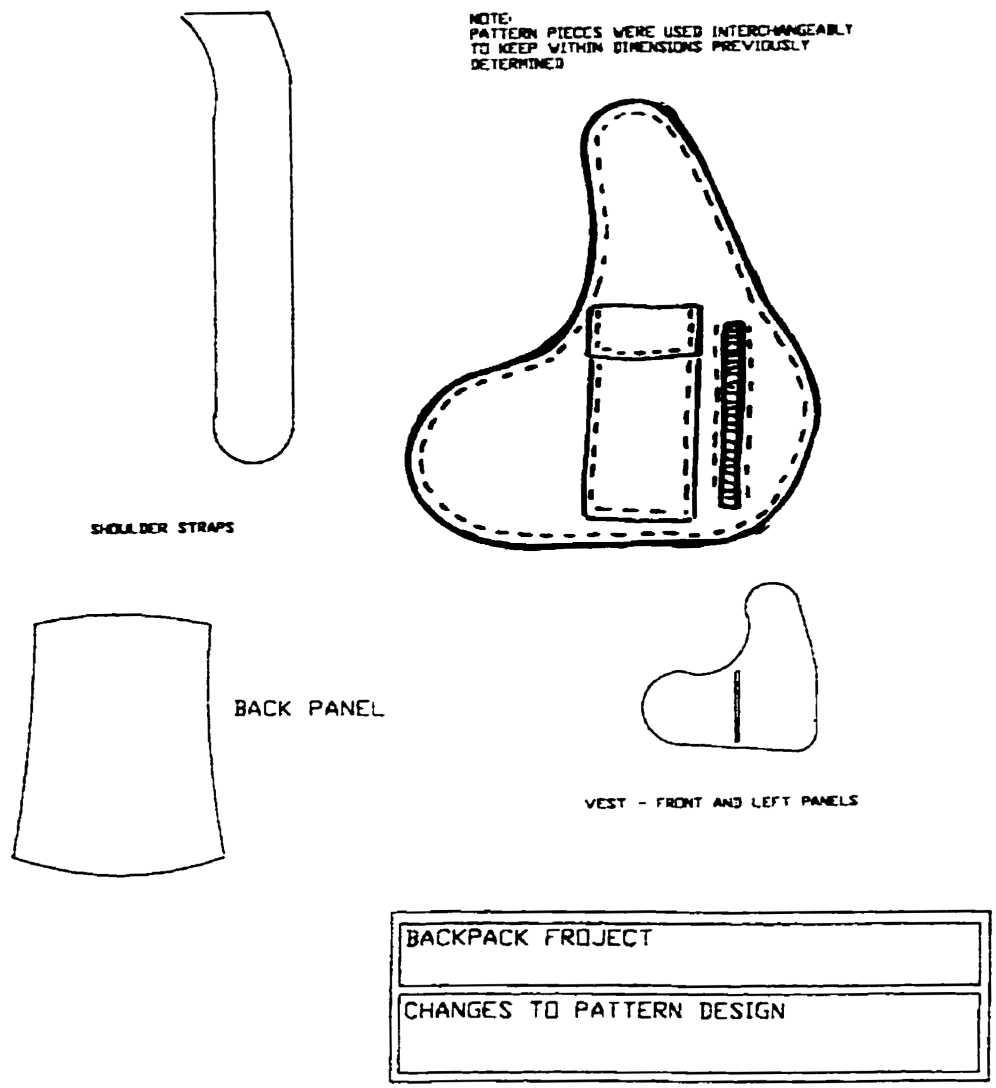
Appendix XIV: CADD Drawing





Appendix XV: CADD Drawing

APPENDIX # 16



Appendix XVI: Changes to Pattern Design

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